# CHAPTER 2

# INDUCTION AND EXHAUST SYSTEMS

## RECIPROCATING ENGINE INDUCTION SYSTEMS

The induction system of an aircraft reciprocating engine consists of a carburetor, an airscoop or ducting that conducts air to the carburetor, and an intake manifold. These units form a long curved channel which conducts air and the fuel/air mixture to the cylinders.

These three units of a typical induction system are usually supplemented by a temperature-indicating system and temperature-controlling unit in some form of alternate air valve and a carburetor heat source. Additionally, a system for compressing the fuel/air mixture may be included.

Since many engines installed in light aircraft do not use any type of compressor or supercharging device, induction systems for reciprocating engines can be broadly classified as supercharged or naturally aspirated (nonsupercharged).

### Nonsupercharged Induction Systems

The nonsupercharged engine is commonly used in light aircraft. The induction systems of these engines may be equipped with either a carburetor or a fuel-injection system. If a carburetor is used, it may be a float-type or a pressure-type carburetor. If fuel injection is used, it will normally be either a constant flow or a pulsed system.

Figure 2–1 is a diagram of an induction system used in a nonsupercharged engine equipped with a carburetor. In this induction system, carburetor cold air is admitted at the leading edge of the nose cowling below the propeller spinner, and is passed through an air filter into air ducts leading to the carburetor. An air valve is located at the carburetor for selecting an alternate warm air source to prevent carburetor icing.

The cold-air valve admits air from the outside air scoop for normal operation and is controlled by a control knob in the cockpit. The warm-air valve admits warm air from the engine compartment for operation during icing conditions and is spring loaded to the "closed" position. When the cold air door is closed, engine suction opens the spring-loaded warm-air valve. If the engine should backfire with the warm-air valve open, spring tension automatically closes the warm-air valve to keep flames out of the engine compartment.

The carburetor air filter is installed in the air scoop in front of the carburetor air duct. Its purpose is to stop dust and other foreign matter from entering the engine through the carburetor. The screen consists of an aluminum alloy frame and a deeply crimped screen, arranged to present maximum screen area to the airstream.

The carburetor air ducts consist of a fixed duct riveted to the nose cowling and a flexible duct between the fixed duct and the carburetor air valve. The carburetor air ducts provide a passage for cold, outside air to the carburetor.

Air enters the system through the ram-air intake. The intake opening is located in the slipstream so the air is forced into the induction system, giving a *ram effect.*

The air passes through the ducts to the carburetor. The carburetor meters the fuel in proportion to the air and mixes the air with the correct amount of fuel. The carburetor can be controlled from the cockpit to regulate the flow of air and, in this way, power output of the engine can be controlled.

The carburetor air temperature indicating system shows the temperature of the air at the carburetor inlet. If the bulb is located at the engine side of the carburetor, the system measures the temperature of the fuel/air mixture.

### Additional Units of the Induction System

The units of a typical induction system previously discussed satisfy the needs of the engine insofar as its ability to produce power is concerned. There are two additional units that add nothing to help the engine do its work but are vital to efficient engine operation. One unit is the preheater; the other is the fluid deicing unit.

Induction system ice can be prevented or eliminated by raising the temperature of the air that passes through the system, using a preheater lo-

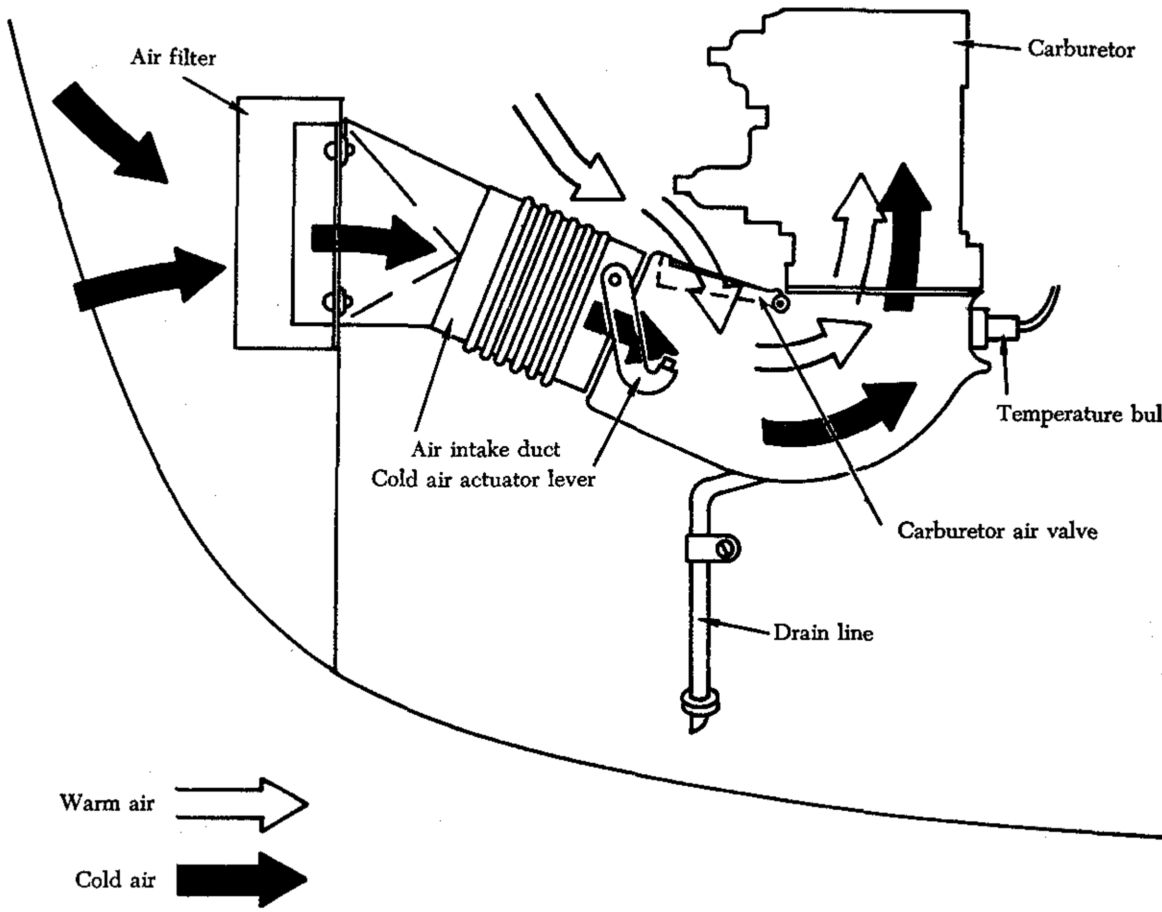



FIGURE 2–1. Nonsupercharged induction system using a carburetor.

cated upstream near the induction system inlet and well ahead of the dangerous icing zones. Heat is usually obtained through a control valve that opens the induction system to the warm air circulating in the engine compartment. When there is danger of induction system icing, move the cockpit control toward the "hot" position until a carburetor air temperature is obtained that will provide the necessary protection.

Throttle ice or any ice that restricts airflow or reduces manifold pressure can best be removed by using full carburetor heat. If the heat from the engine compartment is sufficient and the application has not been delayed, it is only a matter of a few minutes until the ice is cleared. If the air temperature in the engine compartment is not high enough to be effective against icing, the preheat capacity can be increased by closing the cowl flaps and increasing engine power. However, this may prove ineffective if the ice formation has progressed so far that the loss of power makes it impossible to generate sufficient heat to clear the ice.

Improper or careless use of carburetor heat can be just as dangerous as the most advanced stage of induction system ice. Increasing the temperature of the air causes it to expand and decrease in density. This action reduces the weight of the charge delivered to the cylinder and causes a noticeable loss in power because of decreased volumetric efficiency. In addition, high intake air temperature may cause detonation and engine failure, especially during takeoff and high-power operation. Therefore, during all phases of engine operation, the carburetor temperature must afford the greatest protection against icing and detonation. When there is no danger of icing, the heat control is normally kept in the "cold" position. It is best to leave the control in this position if there are particles of dry snow or ice in the air. The use of heat may melt the ice or snow, and the resulting moisture may collect and freeze on the walls of the induction system.

To prevent damage to the heater valves in the case of backfire, carburetor heaters should not be used while starting the engine. Also, during ground operation only enough carburetor heat should be used to give smooth engine operation. The carburetor air inlet temperature gage must be monitored to be sure the temperature does not exceed the maximum value specified by the engine manufacturer.

On some aircraft the basic deicing system is supplemented by a fluid deicing system. This auxiliary system consists of a tank, a pump, suitable spray nozzles in the induction system, and a cockpit control unit. This system is intended to clear ice whenever the heat from the engine compartment is not high enough to prevent or remove ice. The use of alcohol as a deicing agent tends to enrich the fuel mixture, but at a high-power output such slight enrichment is desired. At low throttle settings, however, the use of alcohol may over-enrich the mixture; therefore, alcohol should be applied with great care.

## INDUCTION SYSTEM ICING

A short discussion concerning the formation and the place of formation of induction system ice (fig. 2–2) is helpful to the mechanic, even though he is not normally concerned with operations that occur only when the aircraft is in flight. But the mechanic should know something about induction system icing because of its effect on engine performance. Even when inspection shows that everything is in proper working order, induction system ice can cause an engine to act erratically and lose power in the air, yet the engine will perform perfectly on the ground. Many engine troubles commonly attributed to other sources are actually caused by induction system icing.

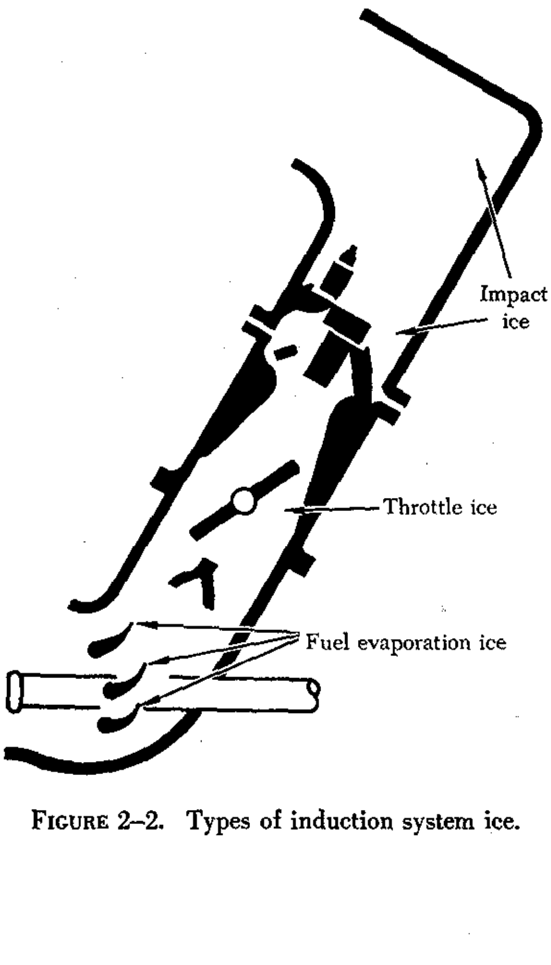



FIGURE 2–2. Types of induction system ice.

Induction system icing is an operating hazard because it can cut off the flow of the fuel/air charge or vary the fuel/air ratio. Ice can form in the induction system while an aircraft is flying in clouds, fog, rain, sleet, snow, or even clear air that has a high moisture content (high humidity). Induction system icing is generally classified in three types: (1) Impact ice, (2) fuel evaporation ice, and (3) throttle ice. Chapter 3 discusses types of icing in more detail.

To understand why part-throttle operation can lead to icing, the throttle area during this operation must be examined. When the throttle is placed in a partly closed position, it, in effect, limits the amount of air available to the engine. The glide which windmills a fixed-pitch propeller causes the engine to consume more air than it normally would at this same throttle setting, thus aggravating the lack of air behind the throttle. The partly closed throttle, under these circumstances, establishes a much higher than normal air velocity past the throttle, and an extremely low pressure area is produced. The low-pressure area lowers the temperature of the air surrounding the throttle valves by the same physical law that raises the temperature of air as it is compressed. If the temperature in this air falls below freezing and moisture is present, ice will form on the throttles and nearby units in much the same manner that impact ice forms on units exposed to below freezing temperatures.

Throttle ice may be minimized on engines equipped with controllable-pitch propellers by the use of a higher than normal BMEP (brake mean effective pressure) at this low power. The high BMEP decreases the icing tendency because a large throttle opening at low engine r.p.m. partially removes the temperature-reducing obstruction that part-throttle operation offers.

### Induction System Filtering

While dust is merely an annoyance to most individuals, it is a serious source of trouble to an aircraft engine. Dust consists of small particles of hard, abrasive material that can be carried into the engine cylinders by the very air the engine breathes. It can also collect on the fuel-metering elements of the carburetor, upsetting the proper relation between airflow and fuel flow at all powers. It acts on the cylinder walls by grinding down these surfaces and the piston rings. It then contaminates the oil and is carried through the engine, causing further wear on the bearings and gears. In extreme cases an accumulation may clog an oil passage and cause oil starvation.

Although dust conditions are most critical at ground level, dust of sufficient quantity to obscure a pilot's vision has been reported in flight. In some parts of the world, dust can be carried to extremely high altitudes. Continued operation under such conditions without engine protection will result in extreme engine wear and produce excessive oil consumption.

When operation in dusty atmosphere is necessary, the engine can be protected by an alternate induction system air inlet which incorporates a dust filter. This type of air filter system normally consists of a filter element, a door, and an electrically operated actuator. When the filter system is operating, air is drawn through a louvered access panel that does not face directly into the airstream. With this entrance location, considerable dust is removed as the air is forced to turn and enter the duct. Since the dust particles are solid, they tend to continue in a straight line, and most of them are separated at this point. Those that are drawn into the louvers are easily removed by the filter.

In flight, with air filters operating, consideration must be given to possible icing conditions which may occur from actual surface icing or from freezing of the filter element after it becomes rainsoaked. Some installations have a spring-loaded filter door which automatically opens when the filter is excessively restricted. This prevents the airflow from being cut off when the filter is clogged with ice or dirt. Other systems use an ice guard in the filtered-air entrance.

The ice guard consists of a coarse-mesh screen located a short distance from the filtered-air entrance. In this location the screen is directly in the path of incoming air so that the air must pass through or around the screen. When ice forms on the screen, the air, which has lost its heavy moisture particles, will pass around the iced screen and into the filter element.

The efficiency of any filter system depends upon proper maintenance and servicing. Periodic removal and cleaning of the filter element is essential to satisfactory engine protection.

#### Induction System Inspection and Maintenance

The induction system should be checked for cracks and leaks during all regularly scheduled engine inspections. The units of the system should be checked for security of mounting. The system should be kept clean at all times, since pieces of rags or paper can restrict the airflow if allowed to enter the air intakes or ducts, and loose bolts and nuts can cause serious damage if they pass into the engine.

On systems equipped with a carburetor air filter, the filter should be checked regularly. If it is dirty or does not have the proper oil film, the filter element should be removed and cleaned. After it has dried, it is usually immersed in a mixture of oil and rust-preventive compound. The excess fluid should be allowed to drain off before the filter element is reinstalled.

#### Induction System Troubleshooting

The following chart provides a general guide to the most common induction system troubles.

| PROBABLE CAUSE | ISOLATION PROCEDURE | CORRECTION |
|---|---|---|
| **1. Engine fails to start—** | | |
| (a) Induction system obstructed. | (a) Inspect airscoop and air ducts. | (a) Remove obstructions. |
| (b) Air leaks. | (b) Inspect carburetor mounting and intake pipes. | (b) Tighten carburetor and repair or replace intake pipe. |
| **2. Engine runs rough—** | | |
| (a) Loose air ducts. | (a) Inspect air ducts. | (a) Tighten air ducts. |
| (b) Leaking intake pipes. | (b) Inspect intake pipe packing nuts. | (b) Tighten nuts. |

| PROBABLE CAUSE | ISOLATION PROCEDURE | CORRECTION |
|---|---|---|
| (c) Engine valves sticking. | (c) Remove rocker arm cover and check valve action. | (c) Lubricate and free sticking valves. |
| (d) Bent or worn valve push rods. | (d) Inspect push rods. | (d) Replace worn or damaged push rods. |
| **3. Low power—** | | |
| (a) Restricted intake duct. | (a) Examine intake duct. | (a) Remove restrictions. |
| (b) Broken door in carburetor air valve. | (b) Inspect air valve. | (b) Replace air valve. |
| (c) Dirty air filter. | (c) Inspect air filter. | (c) Clean air filter. |
| **4. Engine idles improperly—** | | |
| (a) Shrunken intake packing. | (a) Inspect packing for proper fit. | (a) Replace packing. |
| (b) Hole in intake pipe. | (b) Inspect intake pipes. | (b) Replace defective intake pipes. |
| (c) Loose carburetor mounting. | (c) Inspect mount bolts. | (c) Tighten mount bolts. |

### Supercharged Induction Systems

Supercharging systems used in reciprocating engine induction systems are normally classified as either internally driven or externally driven (turbosupercharged).

Internally driven superchargers compress the fuel/air mixture after it leaves the carburetor, while externally driven superchargers (turbochargers) compress the air before it is mixed with the metered fuel from the carburetor. Each increase in the pressure of the air or fuel/air mixture in an induction system is called a stage. Superchargers can be classified as single-stage, two-stage, or multi-stage, depending on the number of times compression occurs. Superchargers may also operate at different speeds. Thus, they can be referred to as single-speed, two-speed, or variable-speed superchargers.

Combining the methods of classification provides the nomenclature normally used to describe supercharger systems. Thus, from a simple single-stage system that operates at one fixed speed ratio, it is possible to progress to a single-stage, two-speed, mechanically clutched system or a single-stage, hydraulically clutched supercharger. Even though two-speed or multi-speed systems permit varying the output pressure, the system is still classified as a single-stage of compression if only a single impeller is used, since only one increase (or decrease) in compression can be obtained at a time.

### INTERNALLY DRIVEN SUPERCHARGERS

Internally driven superchargers are used almost exclusively in high-horsepower reciprocating engines. Except for the construction and arrangement of the various types of superchargers, all induction systems with internally driven superchargers are almost identical. The reason for this similarity is that all modern aircraft engines require the same air temperature control to produce good combustion in the engine cylinders. For example, the temperature of the charge must be warm enough to ensure complete fuel vaporization and, thus, even distribution; but at the same time it must not be so hot that it reduces volumetric efficiency or causes detonation. With these requirements, all induction systems that use internal-driven superchargers must include pressure and temperature-sensing devices and the necessary units required to warm or cool the air.

### Single-Stage, Single-Speed Supercharger Systems

The simple induction system shown in figure 2–3 is used to explain the location of units and the path of the air and fuel/air mixture.

Air enters the system through the ram air intake. The intake opening is located so that the air is forced into the induction system, giving a ram effect.

The air passes through ducts to the carburetor. The carburetor meters the fuel in proportion to the

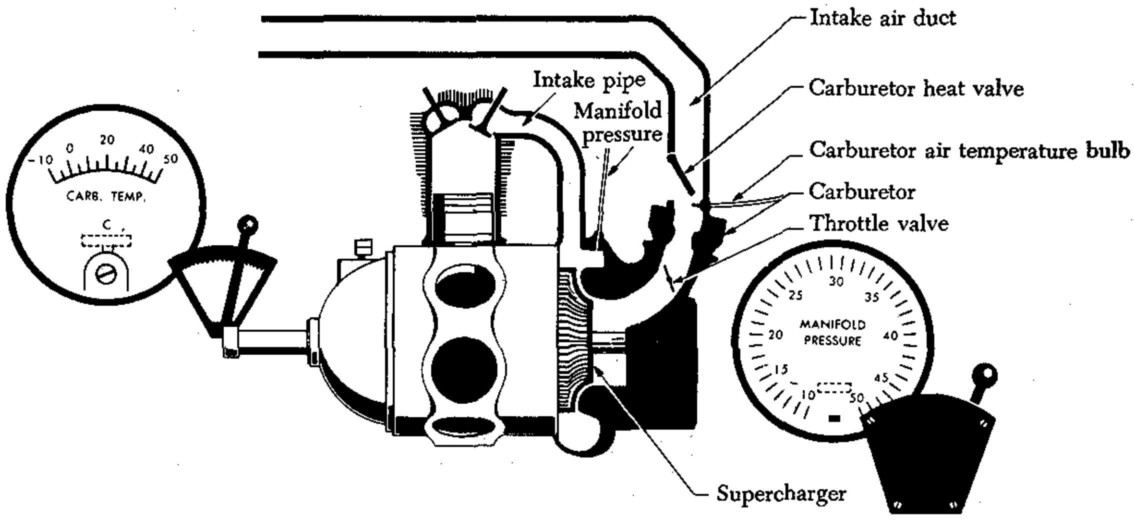



FIGURE 2–3. Simple induction system.

air and mixes the air with the correct amount of fuel. The carburetor can be controlled from the cockpit to regulate the flow of air. In this way, the power output of the engine can be controlled.

The manifold pressure gage measures the pressure of the fuel/air mixture before it enters the cylinders. It is an indication of the performance that can be expected of the engine.

The carburetor air temperature indicator measures either the temperature of the inlet air or of the fuel/air mixture. Either the air inlet or the mixture temperature indicator serves as a guide so that the temperature of the incoming charge may be kept within safe limits.

If the temperature of the incoming air at the entrance to the carburetor scoop is 100° F., there will be approximately a 50° F. drop in temperature because of the partial vaporization of the fuel at the carburetor discharge nozzle. Partial vaporization takes place and the air temperature falls due to absorption of the heat by vaporization. The final vaporization takes place as the mixture enters the cylinders where higher temperatures exist.

The fuel, as atomized into the airstream which flows in the induction system, is in a globular form. The problem, then, becomes one of uniformly breaking up and distributing the fuel remaining in globular form to the various cylinders. On engines equipped with a large number of cylinders, the uniform distribution of the mixture becomes a greater problem, especially at high engine speeds when full advantage is taken of large air capacity.

One method of improving fuel distribution is shown in figure 2–4. This device is known as a distribution impeller. The impeller is attached directly to the end of the rear shank of the crankshaft by bolts or studs. Since the impeller is attached to

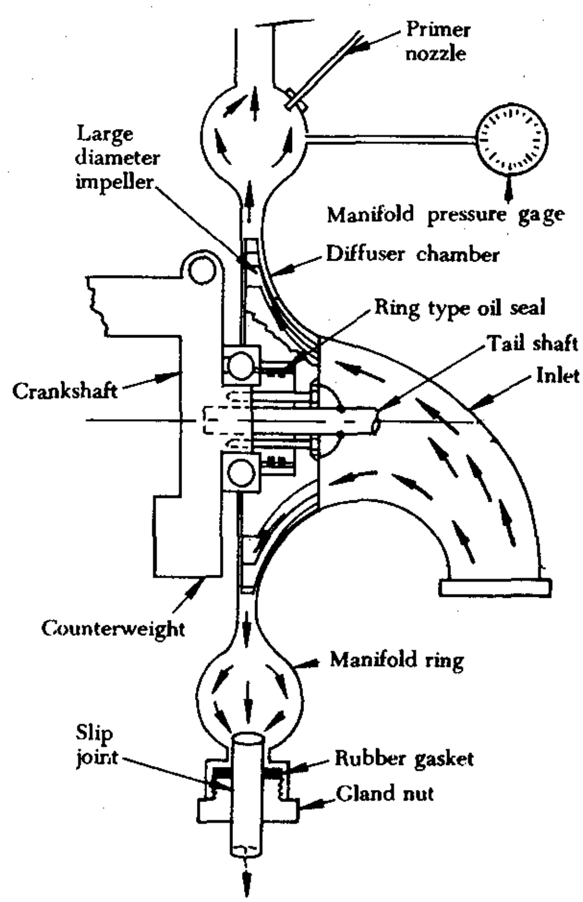



FIGURE 2–4. Distribution impeller arrangement used on a radial engine.

the end of the crankshaft and operates at the same speed, it does not materially boost or increase the pressure on the mixture flowing into the cylinders. But the fuel remaining in the globular form will be broken up into finer particles as it strikes the impeller, thereby coming in contact with more air. This will create a more homogeneous mixture with a consequent improvement in distribution to the various cylinders, especially on acceleration of the engine or when low temperatures prevail.

When greater pressure is desired on the fuel/air mixture in the induction system to charge the cylinders more fully, the diffuser or blower section contains a high-speed impeller. Unlike the distribution impeller, which is connected directly to the crankshaft, the supercharger, or blower impeller, is driven through a gear train from the crankshaft.

The impeller is located centrally within the diffuser chamber. The diffuser chamber surface may be any one of three general designs: (1) Venturi type (figure 2–4), (2) vaned type (A of figure 2–5), or (3) airfoil type (B of figure 2–5).

The venturi-type diffuser is equipped with plain surfaces, sometimes more or less restricted sectionally to form the general shape of a venturi between the impeller tips and the manifold ring. This type has been most widely used on medium-powered, supercharged engines or those in which lower volumes of mixtures are to be handled and where turbulence of the mixture between the impeller tips and the manifold chamber is not critical.

On large-volume engines ranging from 450 hp. upwards, in which the volume of mixture is to be handled at higher velocities and turbulence is a more important factor, either a vane or airfoil type diffuser is widely used. The vanes or airfoil section straightens the airflow within the diffuser chamber to obtain an efficient flow of gases.

The intake pipes on early model engines extended in a direct path from the manifold ring to the intake port on the cylinder. In the more recent designs, however, the intake pipes extend from the manifold ring on a tangent and the pipe is curved as it extends toward the intake port, which has also been streamlined or shaped to promote efficient flow of gases into the cylinder. This reduces turbulence to a minimum. This has been one of the important methods of increasing the breathing capacity or volume of air which a given design of engine might handle. Increases in supercharger efficiency have been one of the major factors in increasing the power output of modern engines.

The gear ratio of the impeller gear train varies from approximately 6:1 to 12:1. Impeller speed on an engine equipped with a 10:1 impeller gear ratio operating at 2,600 r.p.m. would be 26,000 r.p.m. This requires that the impeller unit be a high-grade forging, usually of aluminum alloy, carefully designed and constructed. Because of the high ratio of all supercharger gear trains, considerable acceleration and deceleration forces are created when the engine speed is increased or decreased rapidly. This

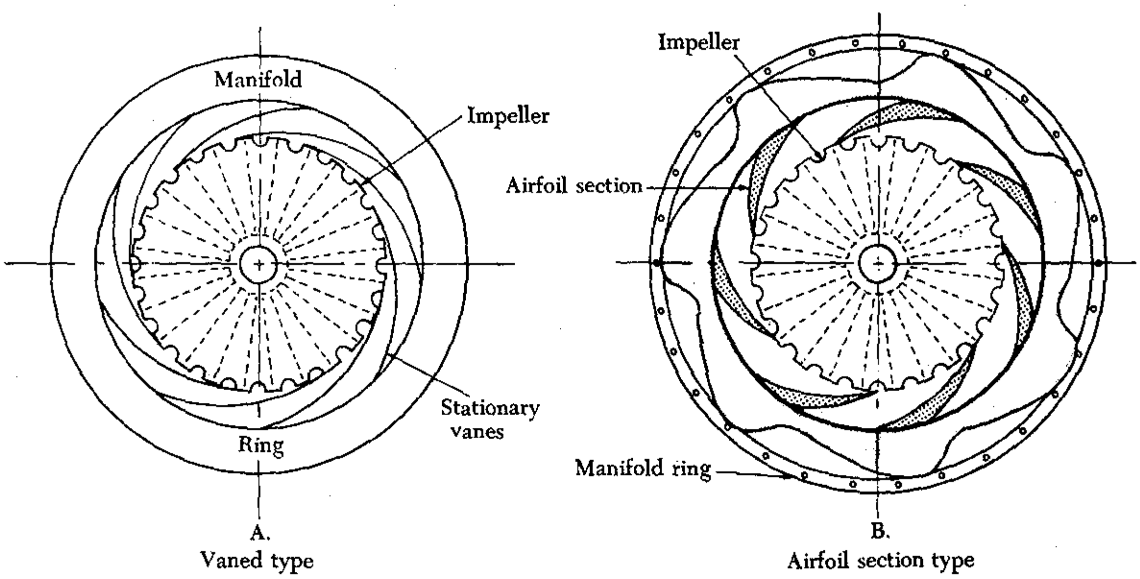



FIGURE 2–5. Supercharger diffuser design (vaned and airfoil section types).

necessitates that the impeller be splined on the shaft. In addition, some sort of spring-loaded or antishock device must be incorporated in the gear train between the crankshaft and impeller.

An oil seal is usually provided around the impeller shaft just forward of the impeller unit. The functions of the seal on this unit are to minimize the passage of lubricating oil and vapors from the crankcase into the diffuser chamber when the engine is idling and to minimize the leakage of the fuel/air mixture into the crankcase when the pressure on the mixture is high at open throttle.

The clearance between the diffuser section and the impeller is obtained by varying the length of the oil seal or the thickness of spacers commonly called shims. Close clearance is necessary to give the greatest possible compression of the mixture and to eliminate, insofar as possible, leakage around the fore and aft surfaces of the impeller. The impeller shaft and intermediate drive shaft assemblies may be mounted on antifriction ball or roller bearings or on friction-type bushings.

The impeller shaft and gear are usually forged integrally of very high grade steel. The impeller end of the shaft is splined to give as much driving surface as possible. The intermediate shaft and large and small gears also are one piece. Both of these units are held within very close running balance or dynamic limits due to the high speeds and stresses involved.

### Single-Stage, Two-Speed Supercharger Systems

Some aircraft engines are equipped with internally driven superchargers which are single-stage, two-speed systems. The impeller in such systems can be driven at two different speeds by means of clutches. A schematic of such a supercharger is shown in figure 2–6.

This unit is equipped with a means of driving the impeller directly from the crankshaft at a ratio of 10:1, which is accomplished by moving the control in the cockpit, thereby applying oil pressure through the high-speed clutch and thus locking the entire intermediate gear assembly. This is called "high blower" and is used above a specified altitude ranging from 7,000 to 12,000 ft. Below these levels, the control is positioned to release the pressure on the high-speed clutch and apply it to the low-speed clutch. This locks the sun pinion of the small planetary gear. The impeller then is driven through the spider and shaft assembly on which the planetary pinions are caused to rotate by the large bell gear. In this case, the impeller is driven at a ratio of approximately 7:1 relative to crankshaft speed. (See figure 2–7.) This condition is called "low blower" and is used during takeoff and for all altitudes below those at which best efficiency can be obtained in "high blower."

In effect, this gives two engines in one. It improves the power output characteristics over a range of operating conditions varying from sea level to approximately 20,000 ft. Naturally, a device of this kind complicates and increases considerably the initial and maintenance costs of the engine. A higher grade fuel is also required to withstand the additional pressures and, in some cases, higher temperatures created within the combustion chamber due to more complete fuel charging of the cylinder. The addition of this unit also complicates the operation of the powerplant because it requires more attention and adds to the variables which must be controlled.

Another example of a two-stage, two-speed supercharger system is shown in figure 2–8, where the blower and intermediate rear sections are opened to show their internal construction. In this example, the blower case supports the engine in the aircraft. It has eight pads on the outer circumference for the engine mounting brackets. A liner in the center of the case accommodates the oil seal rings in the impeller shaft front ring carrier. The blower case houses the impeller, which is driven by clutches at either 7.15 or 8.47 times crankshaft speed. An annulus around the case delivers the fuel and air mixture from the impeller to 14 ports in the case. Attached to each of these ports is an intake pipe through which the fuel and air mixture proceeds to the inlet valve of its cylinder.

### Intermediate Rear Case

The intermediate rear case houses the impeller drive gear train and supports a vaned diffuser (see figure 2–9). The impeller ratio selector valve is mounted on a pad on the top left of the case. From the carburetor mounting flange on the top of the case, a large duct leads down to carry the intake air to the impeller. The fuel transfer pipe from the carburetor connects with a passage in the case behind the carburetor mounting flange. This passage leads to the fuel feed valve. The fuel feed valve delivers fuel to the fuel slinger, which mixes the fuel with the intake air. The cover and diaphragm assembly of the fuel feed valve are mounted on the forward side of the carburetor flange. An accelerating pump is fastened to a pad on the right side of the case just below the carburetor flange. At the lowest point in

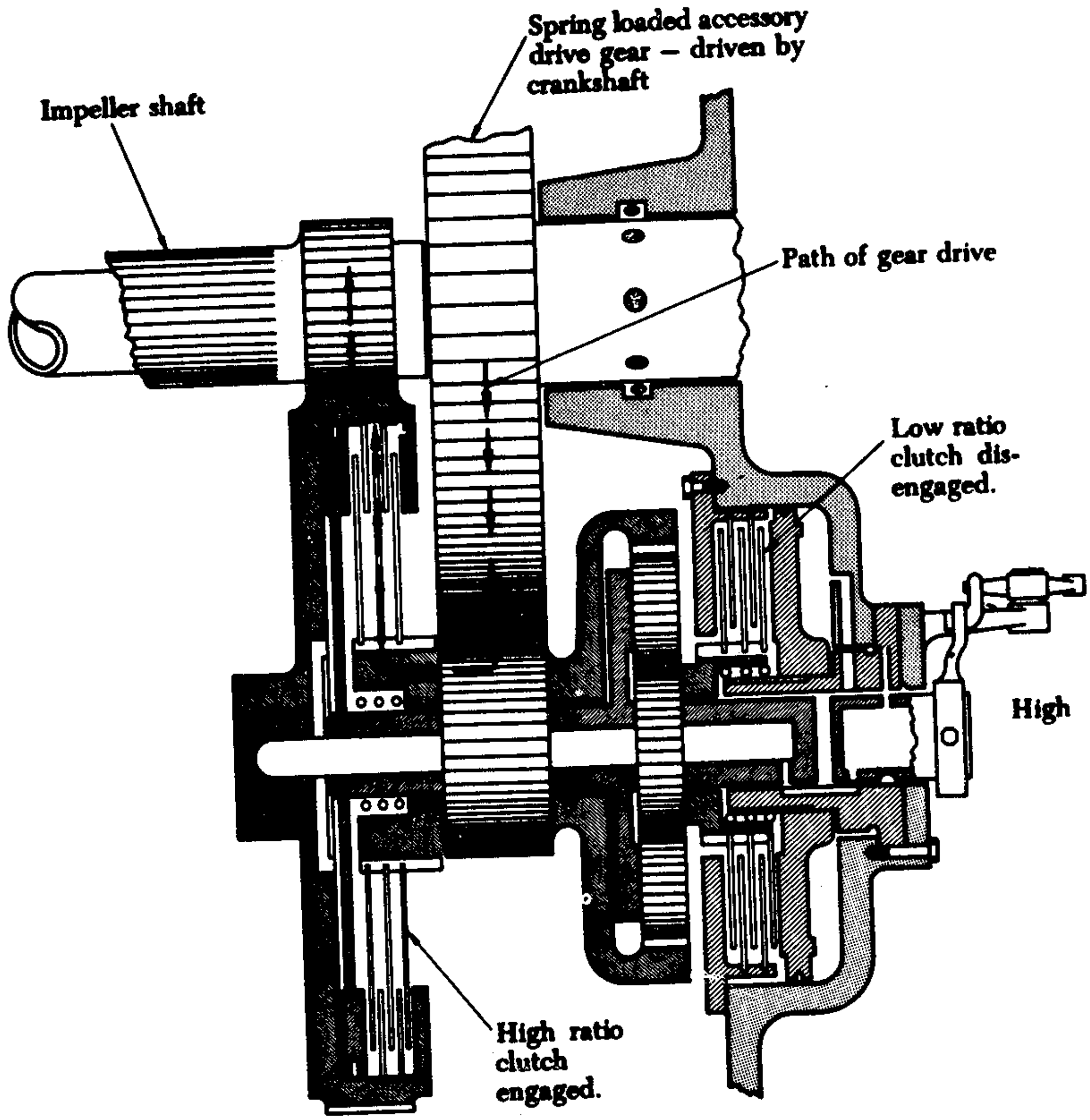



FIGURE 2–6. Schematic diagram of two-speed supercharger in high ratio.

the carburetor air duct, drilled passages lead down to the automatic fuel drain valve in the bottom of the case, which discharges any fuel that may accumulate while the engine is being started.

The intermediate rear case also houses the dual-ratio clutches and the impeller ratio selector valve. Both a high(8.47:1)—and a low(7.15:1)—ratio clutch are mounted on each of two shafts, one on each side of the impeller shaft. These shafts are supported at the front end by bushings in the rear case. The shafts are driven by the accessory drive gear through pinions splined to the shafts. The clutch cones are splined to the clutch shafts and, when engaged, drive the clutch gears, which, in turn, drive the spur gears on the impeller shaft. The selector valve directs pressure oil to oil chambers between the cones and the gears of either the two low or the two high clutches. The oil pressure causes the cones to engage the segments that, in turn, engage the gears of whichever pair of clutches are selected to drive the impeller. Drain oil from the disengaged pair of clutches is forced back through the selector valve and discharged into the intermediate rear case.

To assist in cleaning sludge out of the clutches, each clutch gear is equipped with a creeper gear having one more tooth than the clutch gear. A bleed hole in the creeper gear itself alines momentarily with each of the bleed holes in the corresponding clutch gear. The pressure oil within the engaged clutch spurts out, carrying the sludge with it.

## EXTERNALLY DRIVEN SUPERCHARGERS

Externally driven superchargers are designed to deliver compressed air to the inlet of the carburetor or fuel/air control unit of an engine. Externally driven superchargers derive their power from the energy of engine exhaust gases directed against some form of turbine. For this reason, they are commonly called turbosuperchargers or turbochargers.

## TURBOSUPERCHARGER SYSTEM FOR LARGE RECIPROCATING ENGINES

In some high-altitude aircraft the internal supercharger is supplemented by an external turbosupercharger driven by a portion of the exhaust gas from the aircraft engine. This type of supercharger is mounted ahead of the carburetor as shown in figure 2–10 to pressurize the air at the carburetor

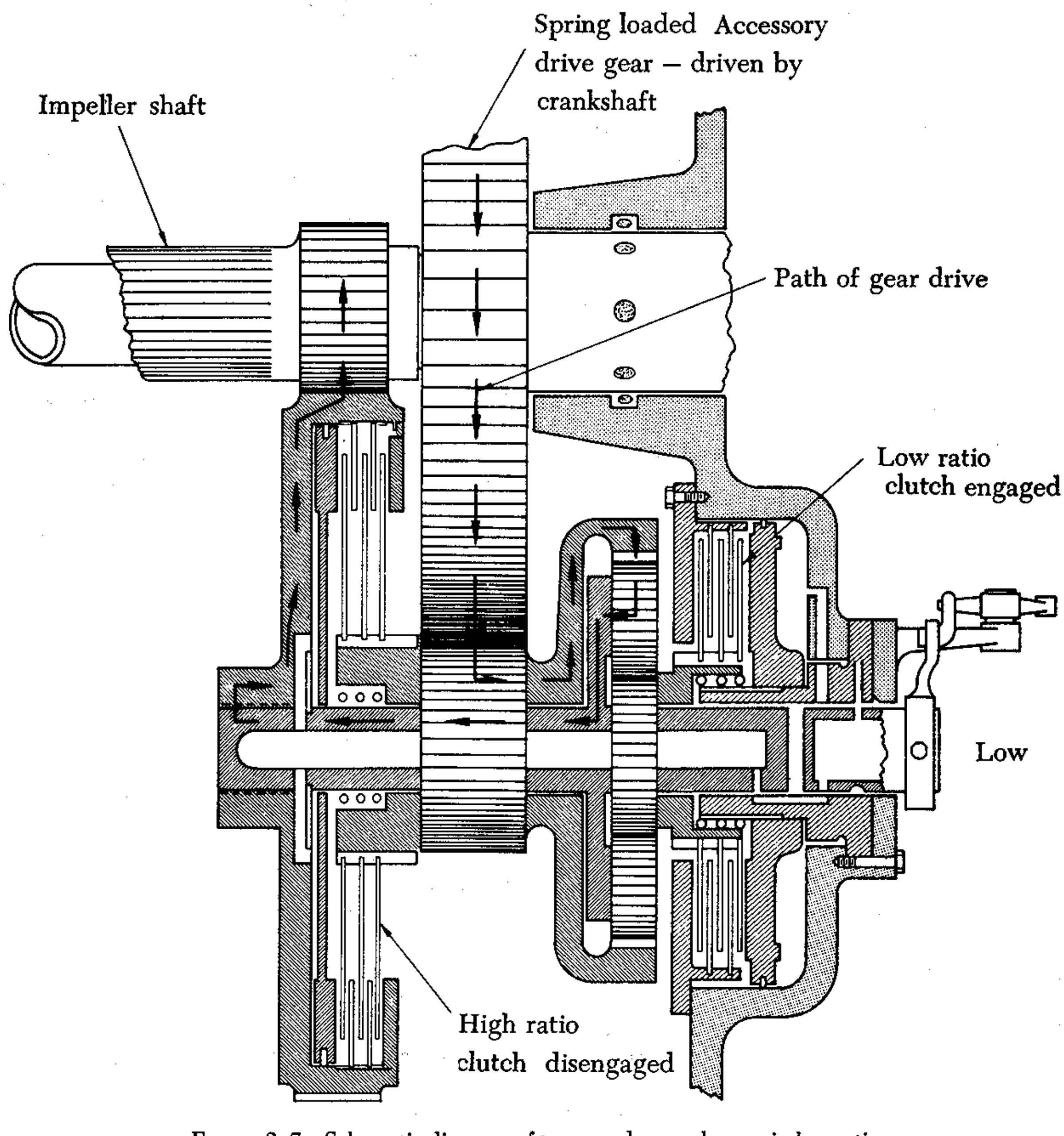



FIGURE 2–7. Schematic diagram of two-speed supercharger in low ratio.

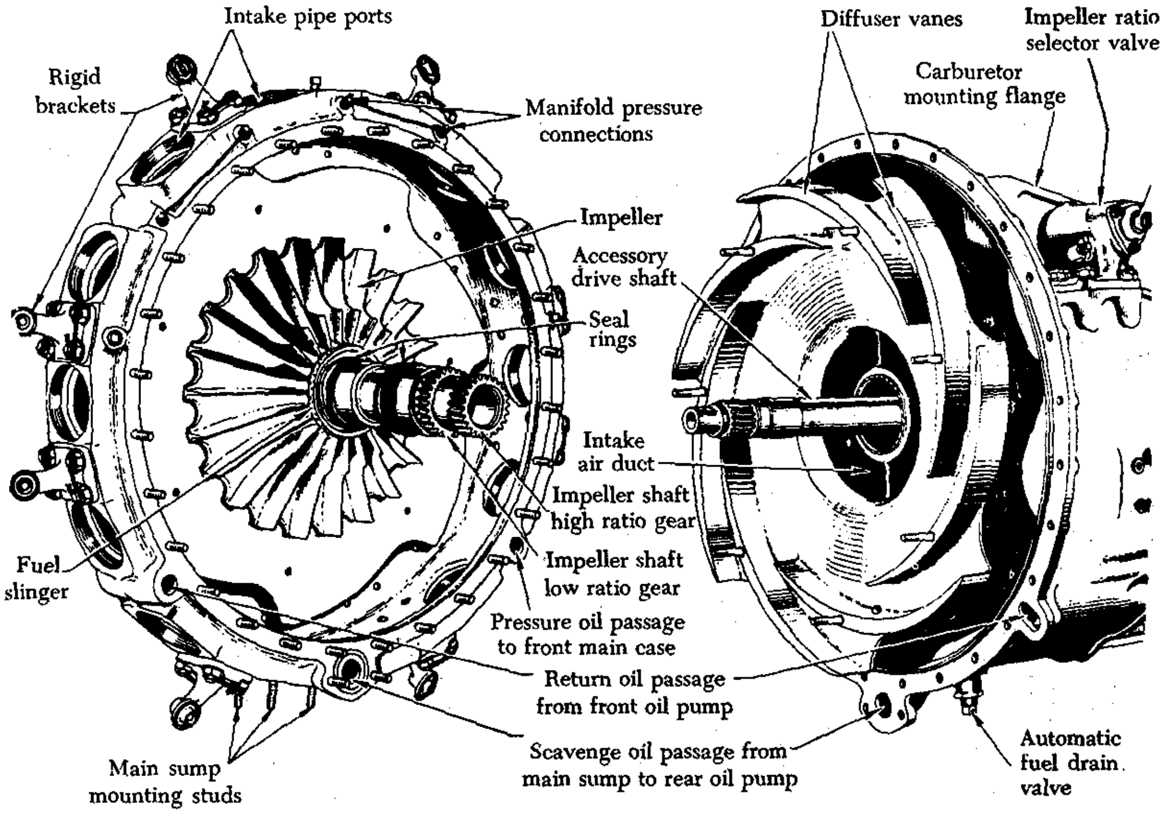



FIGURE 2–8. Blower and intermediate rear sections.

inlet. If the air pressure entering the carburetor is maintained at approximately sea level density throughout the aircraft's climb to altitude, there will be none of the power loss experienced in aircraft not equipped with turbos. However, this type of supercharger imposes an induction system requirement not needed in other supercharger installations. As air moves through the turbo, its temperature is raised because of compression. If the hot air charge is not properly cooled before it reaches the internal supercharger, the second stage of supercharging will produce a final charge temperature that is too great.

The air in turbo-equipped induction systems is cooled by an intercooler (figure 2–10), so called because it cools the charge between compression stages rather than after the last stage. The hot air flows through tubes in the intercooler in much the same manner that water flows in the radiator of an automobile. Fresh outside air, separate from the charge, is collected and piped to the intercooler so that it flows over and cools the tubes. As the induction air charge flows through the tubes, heat is removed and the charge is cooled to a degree that the engine can tolerate without detonation occurring. Control for the cooling air is provided by intercooler shutters which regulate the amount of air that passes over and around the tubes of the intercooler.

The typical turbosupercharger is composed of three main parts:

(1) The compressor assembly.
(2) The exhaust gas turbine assembly.
(3) The pump and bearing casing.

These major sections are shown in figure 2–11. In addition to the major assemblies, there is a baffle between the compressor casing and the exhaust-gas turbine that directs cooling air to the pump and bearing casing, and also shields the compressor from the heat radiated by the turbine. In installations where cooling air is limited, the baffle is replaced by a regular cooling shroud that receives its air directly from the induction system.

The compressor assembly (A of figure 2–11) is made up of an impeller, a diffuser, and a casing. The air for the induction system enters through a circular opening in the center of the compressor casing, where it is picked up by the blades of the impeller, which gives it high velocity as it travels outward toward the diffuser. The diffuser vanes

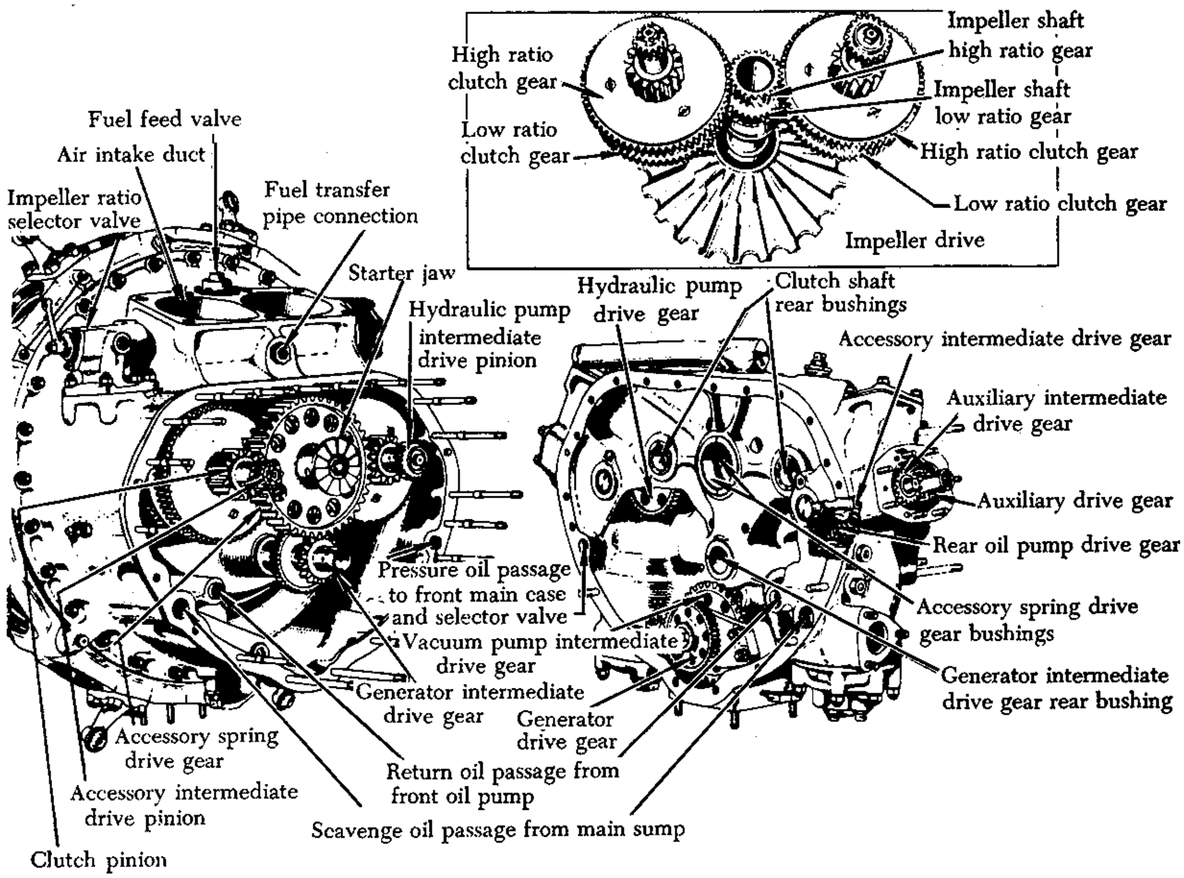



**FIGURE 2–9. Intermediate rear and rear case sections.**

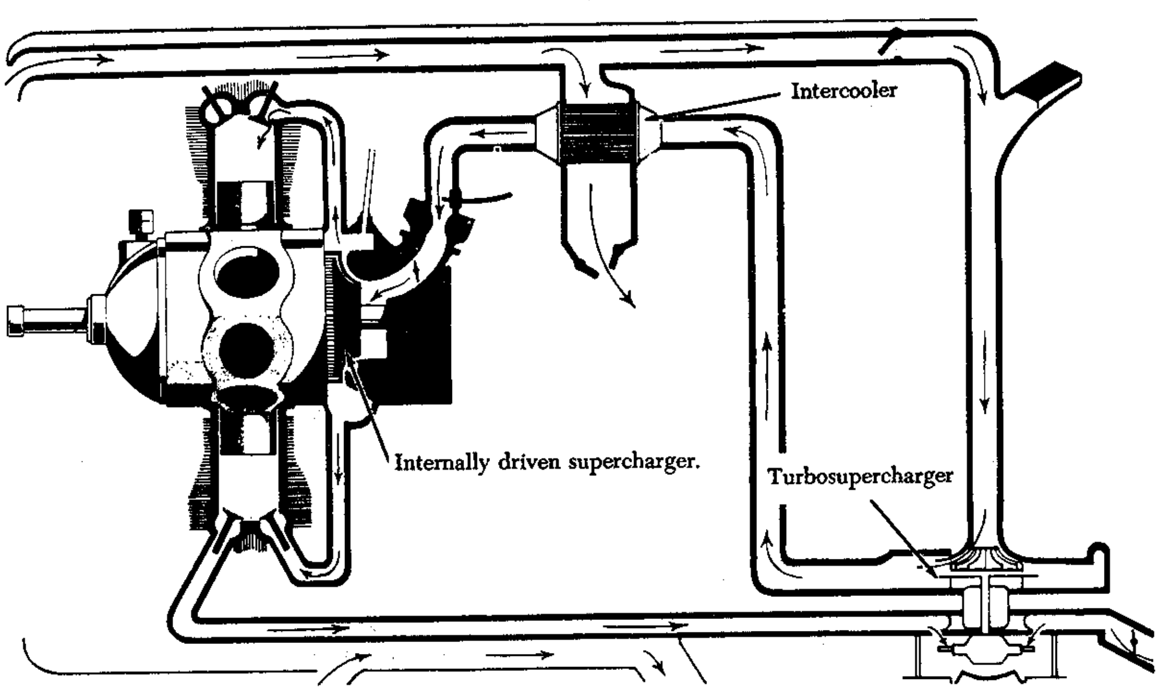
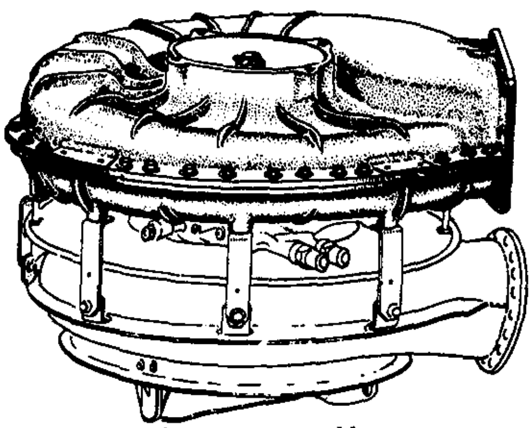


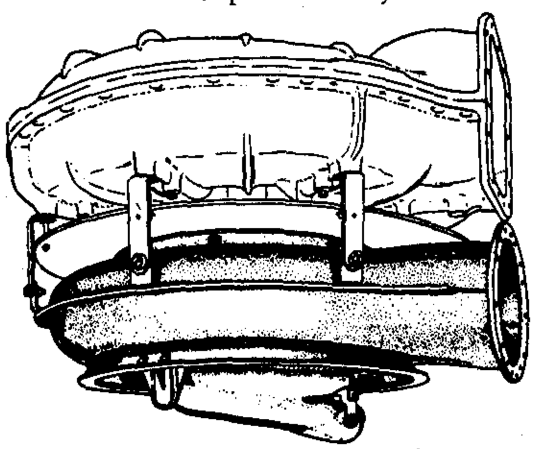

**FIGURE 2–10. Induction system with turbosupercharger.**

direct the airflow as it leaves the impeller and also converts the high velocity of the air to high pressure.

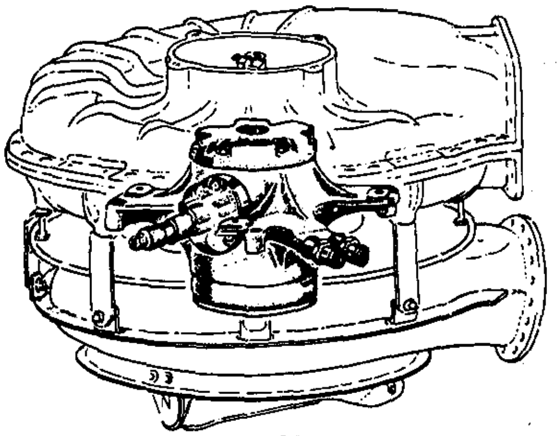
Motive power for the impeller is furnished through the impeller's attachment to the turbine wheel shaft of the exhaust-gas turbine. This complete assembly is referred to as the rotor. The rotor revolves on the ball bearings at the rear end of the pump and bearing casing and the roller bearing at the turbine end. The roller bearing carries the radial (centrifugal) load of the rotor, and the ball bearing supports the rotor at the impeller end and bears the entire thrust (axial) load and part of the radial load.



A. Compressor assembly



B. Exhaust gas turbine assembly



C. Pump and bearing casing

FIGURE 2–11. Main sections of a typical turbosupercharger.

The exhaust gas turbine assembly (B of figure 2–11) consists of the turbine wheel (bucket wheel), nozzle box, butterfly valve (waste gate), and cooling cap. The turbine wheel, driven by exhaust gases, drives the impeller. The nozzle box collects and directs the exhaust gases onto the turbine wheel, and the waste gate regulates the amount of exhaust gases directed to the turbine by the nozzle box. The cooling cap controls a flow of air for turbine cooling.

The waste gate (figure 2–12) controls the volume of the exhaust gas that is directed onto the turbine and thereby regulates the speed of the rotor (turbine and impeller).

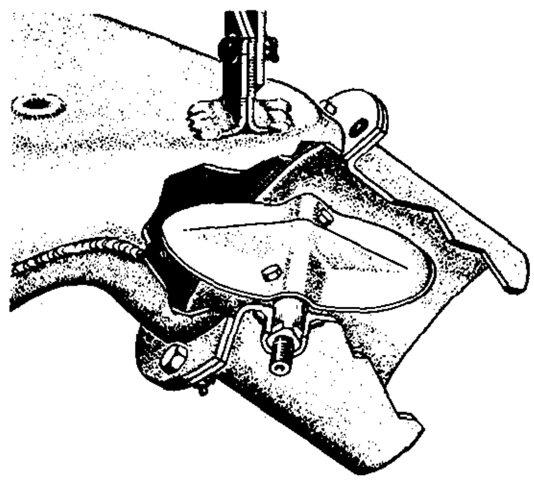


FIGURE 2–12. Waste gate assembly.

If the waste gate is completely closed, all the exhaust gases are "backed up" and forced through the nozzle box and turbine wheel. If the waste gate is partially closed, a corresponding amount of exhaust gas is directed to the turbine. The nozzles of the nozzle box allow the gases to expand and reach high velocity before they contact the turbine wheel. The exhaust gases, thus directed, strike the cuplike buckets, arranged radially around the outer edge of the turbine, and cause the rotor (turbine and impeller) to rotate. The gases are then exhausted overboard through the spaces between the buckets. When the waste gate is fully open, nearly all of the exhaust gases pass overboard through the tailpipe.

## TURBOCHARGER

An increasing number of engines used in light aircraft are equipped with externally driven supercharger systems. These superchargers are powered by the energy of exhaust gases and are usually referred to as "turbocharger" systems rather than "turbosuperchargers."

On many small aircraft engines, the turbocharger system is designed to be operated only above a certain altitude; for example, 5,000 ft., since maximum power without supercharging is available below that altitude.

The location of the air induction and exhaust systems of a typical turbocharger system for a small aircraft is shown in figure 2–13.

### Induction Air System

The induction air system shown in figure 2–14 consists of a filtered ram-air intake located on the side of the nacelle. An alternate air door within the nacelle permits compressor suction to automatically admit alternate air (heated engine compartment air) if the induction filter becomes clogged. The alternate air door can be operated manually in the event of filter clogging. A separately mounted exhaust-driven turbocharger is included in each air induction system. The turbocharger is automatically controlled by a pressure controller, to maintain manifold pressure at approximately 34.5 in. Hg from sea level to the critical altitude (typically 16,000 ft.) regardless of temperature. The turbocharger is completely automatic, requiring no pilot action up to the critical altitude.

### Controllers and Waste-Gate Actuator

The waste-gate actuator and controllers use engine oil for power supply. (Refer to turbocharger system schematic in figure 2–15.) The turbocharger is controlled by the waste gate and waste-gate actuator, an absolute pressure and a rate-of-change controller. A pressure ratio controller controls the waste-gate actuator above critical altitude (16,000 ft.). The waste-gate bypasses the engine exhaust gases around the turbocharger turbine inlet. The waste-gate actuator, which is physically connected to the waste gate by mechanical linkage, controls the position of the waste-gate butterfly valve. The absolute pressure controller and the rate-of-change

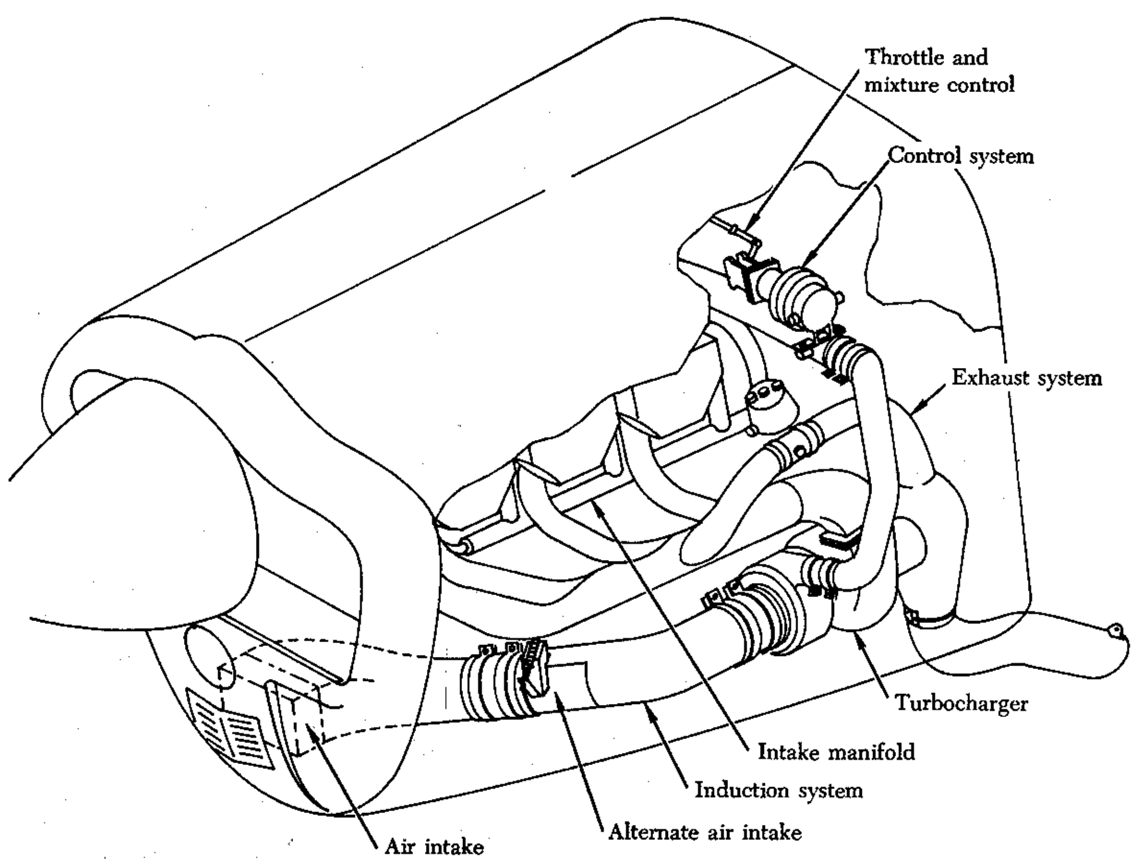



FIGURE 2–13. Turbocharger induction and exhaust systems.

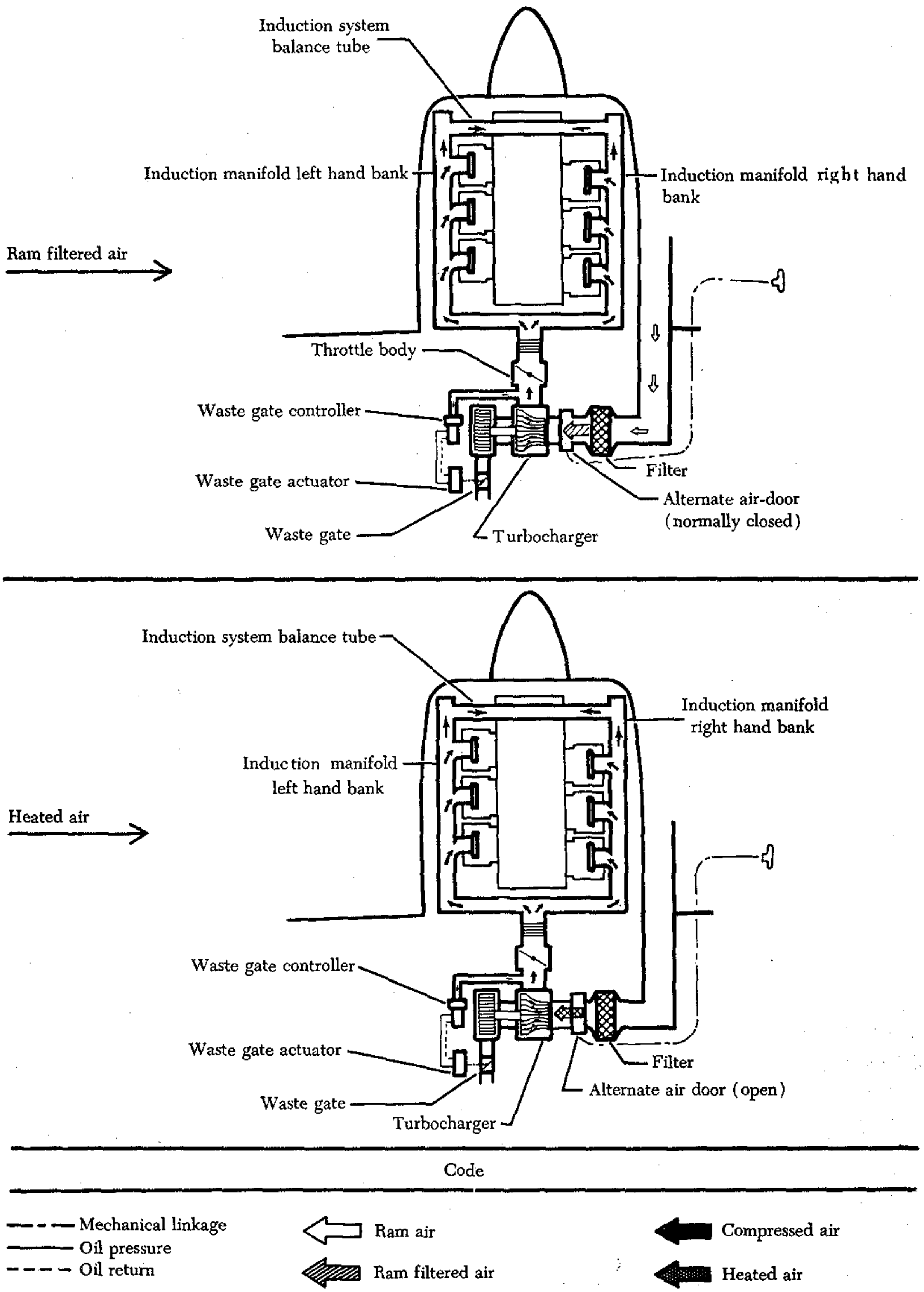



FIGURE 2–14. Induction air system schematic.

controller have a two-fold function: (1) The absolute pressure controller controls the maximum turbocharger compressor discharge pressure (34 ±.5 in. Hg to critical altitude, approximately 16,000 ft.); and (2) the rate-of-change controller controls the rate at which the turbocharger compressor discharge pressure will increase.

## SEA-LEVEL BOOSTED TURBOCHARGER SYSTEM

Some turbocharger systems are designed to operate from sea level up to their critical altitude. These engines, sometimes referred to as sea-level boosted engines, can develop more power at sea level than an engine without turbocharging.

Figure 2–16 is a schematic of a sea level booster turbocharger system. This system is automatically regulated by three components shown in the schematic: (1) The exhaust bypass valve assembly, (2) the density controller, and (3) the differential pressure controller. It should be noted that some turbocharger systems are not equipped with automatic control devices. They are similar in design and operation to the system shown in figure 2–16, except that the turbocharger output is manually controlled.

By regulating the waste gate position and the "fully open" and "closed" positions (figure 2–16), a constant power output can be maintained. When the waste gate is fully open, all the exhaust gases are directed overboard to the atmosphere, and no air is compressed and delivered to the engine air inlet. Conversely, when the waste gate is fully closed, a maximum volume of exhaust gases flows into the turbocharger turbine, and maximum supercharging is accomplished. Between these two extremes of waste gate position, constant power output can be achieved below the maximum altitude at which the system is designed to operate.

A critical altitude exists for every possible power setting below the maximum operating ceiling, and if the aircraft is flown above this altitude without a corresponding change in the power setting, the waste gate will be automatically driven to the "fully closed" position in an effort to maintain a constant power output. Thus, the waste gate will be almost fully open at sea level and will continue to move toward the "closed" position as the aircraft climbs, in order to maintain the preselected manifold pressure setting.

When the waste gate is fully closed (leaving only a small clearance to prevent sticking) the manifold pressure will begin to drop if the aircraft continues to climb. If a higher power setting cannot be selected, the turbocharger's critical altitude has been reached. Beyond this altitude, the power output will continue to decrease.

The position of the waste gate valve, which determines power output, is controlled by oil pressure. Engine oil pressure acts on a piston in the waste gate assembly which is connected by linkage to the waste gate valve. When oil pressure is increased on the piston, the waste gate valve moves toward the "closed" position, and engine output power increases. Conversely, when the oil pressure is decreased, the waste gate valve moves toward the "open" position, and output power is decreased.

The position of the piston attached to the waste gate valve is dependent on bleed oil which controls the engine oil pressure applied to the top of the piston. Oil is returned to the engine crankcase through two control devices, the density controller and the differential pressure controller. These two controllers, acting independently, determine how much oil is bled back to the crankcase, and thus establishes the oil pressure on the piston.

The density controller is designed to limit the manifold pressure below the turbocharger's critical altitude, and regulates bleed oil only at the "full throttle" position. The pressure- and temperature-sensing bellows of the density controller react to pressure and temperature changes between the fuel injector inlet and the turbocharger compressor. The bellows, filled with dry nitrogen, maintains a constant density by allowing the pressure to increase as the temperature increases. Movement of the bellows re-positions the bleed valve, causing a change in the quantity of bleed oil, which changes the oil pressure on top of the waste gate piston. (See figure 2–16.)

The differential pressure controller functions during all positions of the waste gate valve other than the "fully open" position, which is controlled by the density controller. One side of the diaphragm in the differential pressure controller senses air pressure upstream from the throttle; the other side samples pressure on the cylinder side of the throttle valve (figure 2–16). At the "wide open" throttle position when the density controller controls the waste gate, the pressure across the differential pressure controller diaphragm is at a minimum and the controller spring holds the bleed valve closed. At "part throttle" position, the air differential is increased, opening the bleed valve to bleed oil to the engine crankcase and re-position the waste gate piston.

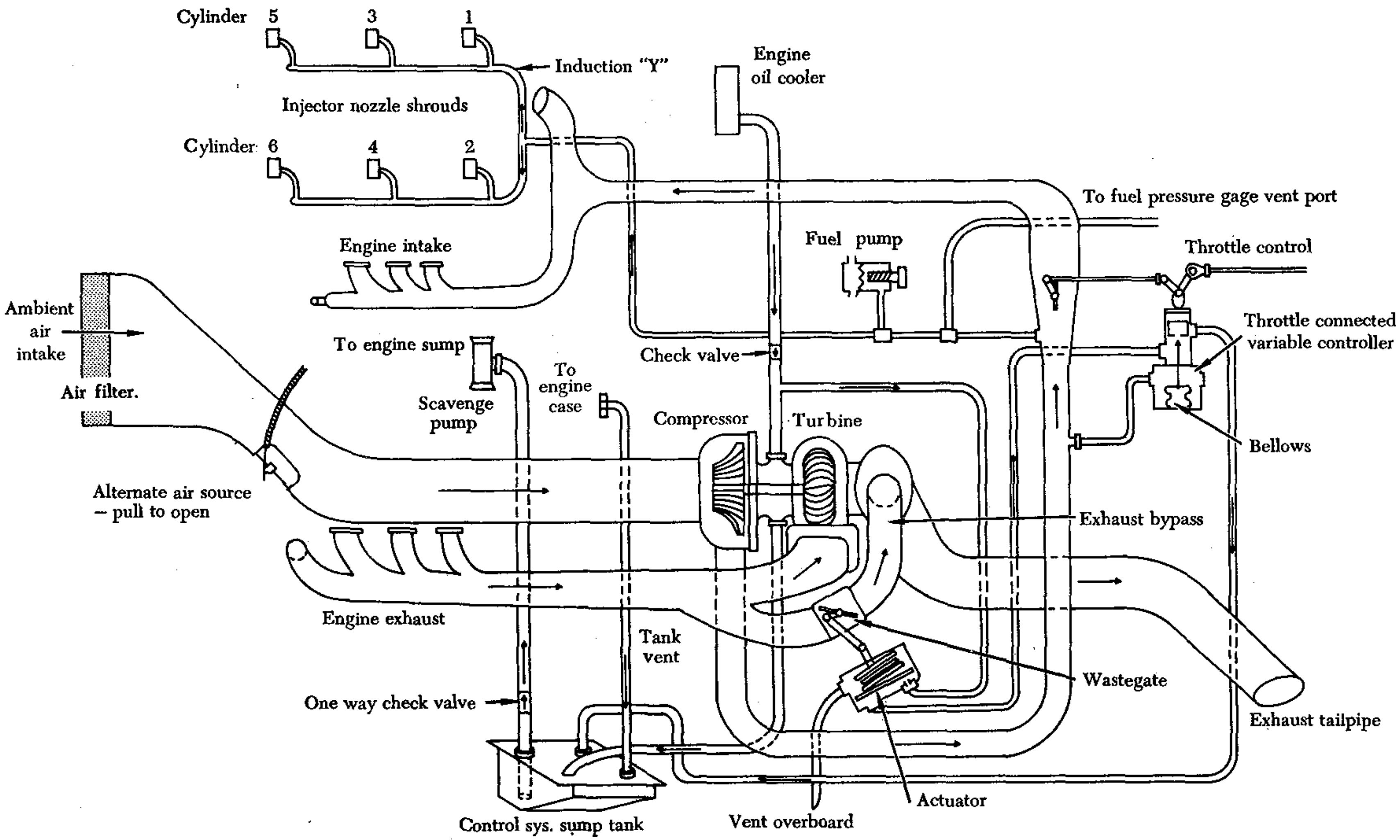



FIGURE 2–15. Schematic of a typical turbocharger system.

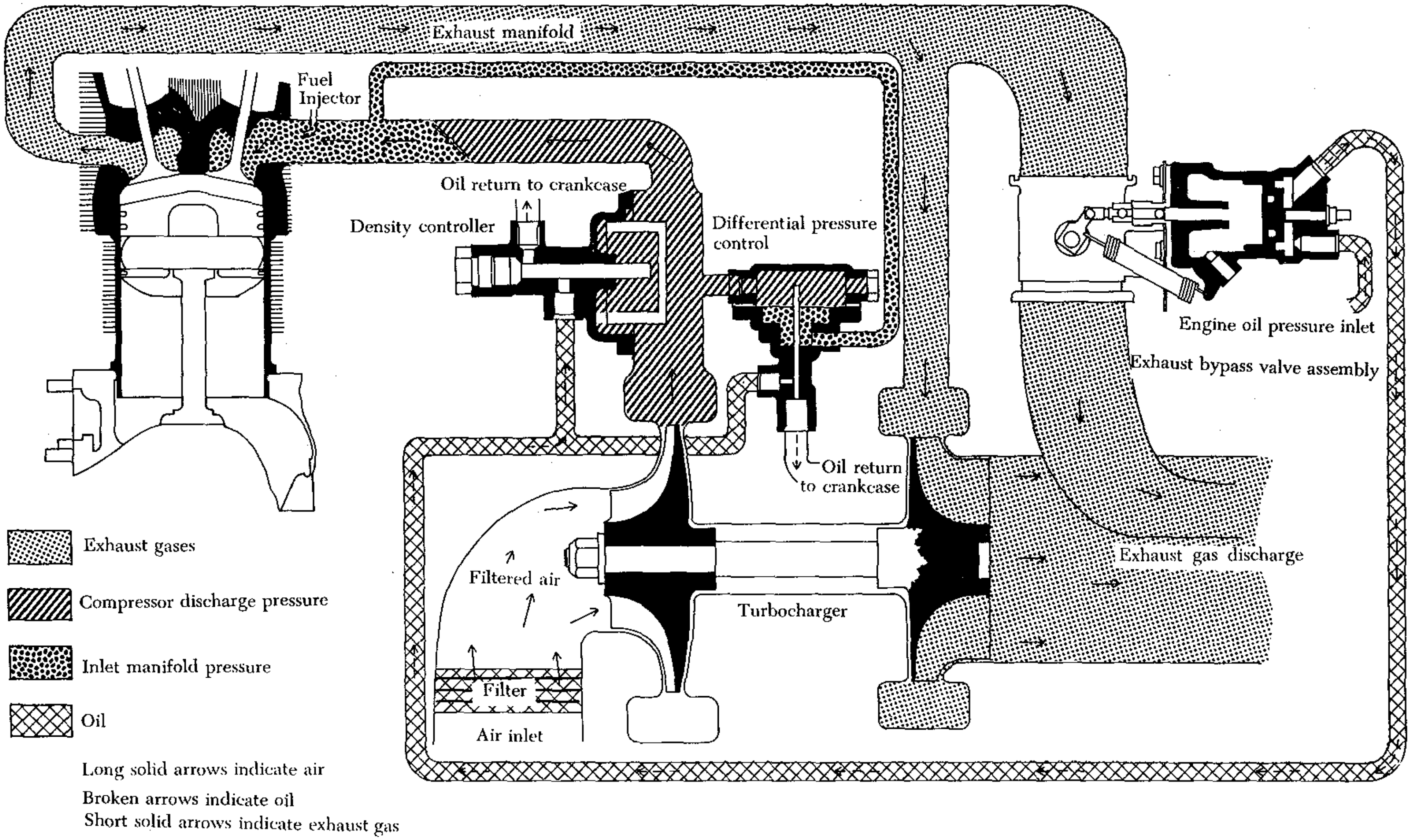



FIGURE 2–16. Turbocharger controllers and waste-gate actuater system schematic.

Thus, the two controllers operate independently to control turbocharger operation at all positions of the throttle. Without the overriding function of the differential pressure controller during part-throttle operation, the density controller would position the waste gate valve for maximum power. The differential pressure controller reduces injector entrance pressure and continually re-positions the valve over the whole operating range of the engine.

The differential pressure controller reduces the unstable condition known as "bootstrapping" during part-throttle operation. Bootstrapping is an indication of unregulated power change that results in the continual drift of manifold pressure. This condition can be illustrated by considering the operation of a system when the waste gate is fully closed. During this time, the differential pressure controller is not modulating the waste gate valve position. Any slight change in power caused by a change in temperature or r.p.m. fluctuation will be magnified and will result in manifold pressure change since the slight change will cause a change in the amount of exhaust gas flowing to the turbine. Any change in exhaust gas flow to the turbine will cause a change in power output and will be reflected in manifold pressure indications. Bootstrapping, then, is an undesirable cycle of turbocharging events causing the manifold pressure to drift in an attempt to reach a state of equilibrium.

Bootstrapping is sometimes confused with the condition known as "overboost," but bootstrapping is not a condition which is detrimental to engine life. An overboost condition is one in which manifold pressure exceeeds the limits prescribed for a particular engine and can cause serious damage.

Thus, the differential pressure controller is essential to smooth functioning of the automatically controlled turbocharger, since it reduces bootstrapping by reducing the time required to bring a system into equilibrium. There is still a great deal more throttle sensitivity with a turbocharged engine than with a naturally aspirated engine. Rapid movement of the throttle can cause a certain amount of manifold pressure drift in a turbocharged engine. This condition, less severe than bootstrapping, is called "overshoot." While overshoot is not a dangerous condition, it can be a source of concern to the pilot or operator who selects a particular manifold pressure setting only to find it has changed in a few seconds and must be reset. Since the automatic controls cannot respond rapidly enough to abrupt changes in throttle settings to eliminate the inertia of turbocharger speed changes, overshoot must be controlled by the operator. This can best be accomplished by slowly making changes in throttle setting, accompanied by a few seconds' wait for the system to reach a new equilibrium. Such a procedure is effective with turbocharged engines, regardless of the degree of throttle sensitivity.

### Turbocharger System Troubleshooting

Table 1 includes some of the most common turbocharger system malfunctions, together with their cause and repair. These troubleshooting procedures are presented as a guide only and should not be substituted for applicable manufacturer's instructions or troubleshooting procedures.

## TURBOCOMPOUND SYSTEMS FOR RECIPROCATING ENGINES

The turbocompound engine consists of a conventional, reciprocating engine in which exhaust-driven turbines are coupled to the engine crankshaft. This system of obtaining additional power is sometimes called a PRT (power recovery turbine) system. It is not a supercharging system, and it is not connected in any manner to the air induction system of the aircraft.

The PRT system enables the engine to recover power from the exhaust gases that would be otherwise directed overboard. Depending on the type of engine, the amount of horsepower recovered varies with the amount of input power. An average of 130 horsepower from each of three turbines in a system is typical for large reciprocating engines.

A power recovery turbine's geared connection to the engine crankshaft is shown in figure 2–17.

Typically there are three power-recovery turbines on each engine, located 120° apart. They are numbered, viewed from the rear of the engine, in a clockwise direction. Number 1 turbine is located in the 3-o'clock position, and number 3 turbine in the 11-o'clock position. Turbine position in relationship to the exhaust system of the various cylinders on an 18-cylinder engine is shown in the schematic of figure 2–18.

The exhaust collector nozzle for each segment of cylinders (figure 2–18) directs the exhaust gases onto the turbine wheel. The turbine wheel shaft transmits the power to the engine crankshaft through gears and a fluid coupling. The fluid coupling prevents torsional vibration from being transmitted to the crankshaft.

Power recovery turbine systems, because of weight and cost considerations, are used exclusively on very large reciprocating engines.

TABLE 1. Troubleshooting turbocharger system.

| *Trouble* | *Probable Cause* | *Remedy* |
|---|---|---|
| Aircraft fails to reach critical altitude. | Damaged compressor or turbine wheel. | Replace turbocharger. |
| | Exhaust system leaks. | Repair leaks. |
| | Faulty turbocharger bearings. | Replace turbocharger. |
| | Waste gate will not close fully. | Refer to "waste gate" in the trouble column. |
| | Malfunctioning controller. | Refer to "differential controller" in the trouble column. |
| Engine surges. | Bootstrapping. | Ensure engine is operated in proper range. |
| | Waste gate malfunction. | Refer to "waste gate" in the trouble column. |
| | Controller malfunction. | Refer to "differential controller" in the trouble column. |
| Waste gate will not close fully. | Waste gate bypass valve bearings tight. | Replace bypass valve. |
| | Oil inlet orifice blocked. | Clean orifice. |
| | Controller malfunction. | Refer to "controller" in the trouble column. |
| | Broken waste gate linkage. | Replace linkage and adjust waste gate for proper opening and closing. |
| Waste gate will not open. | Oil outlet obstructed. | Clean and reconnect oil return line. |
| | Broken waste gate linkage. | Replace linkage and adjust waste gate opening and closing. |
| | Controller malfunction. | Refer to "controller" in the trouble column. |
| Differential controller malfunctions. | Seals leaking. | Replace controller. |
| | Diaphragm broken. | Replace controller. |
| | Controller valve stuck. | Replace controller. |
| Density controller malfunctions. | Seals leaking. | Replace controller. |
| | Bellows damaged. | Replace controller. |
| | Valve stuck. | Replace controller. |

## TURBOJET ENGINE INLET DUCT SYSTEMS

Although no direct parallel can be drawn, the turbine engine air-inlet duct is somewhat analogous to the air induction system of reciprocating engines.

The engine inlet and the inlet ducting of a turbine engine furnish a relatively distortion-free, high-energy supply of air, in the required quantity, to the face of the compressor. A uniform and steady airflow is necessary to avoid compressor stall and excessive internal engine temperatures at the turbine. The high energy enables the engine to produce an optimum amount of thrust. Normally, the air-inlet duct is considered an airframe part, and not a part of the engine. However, the duct is so important to engine performance that it must be considered in any discussion of the complete engine.

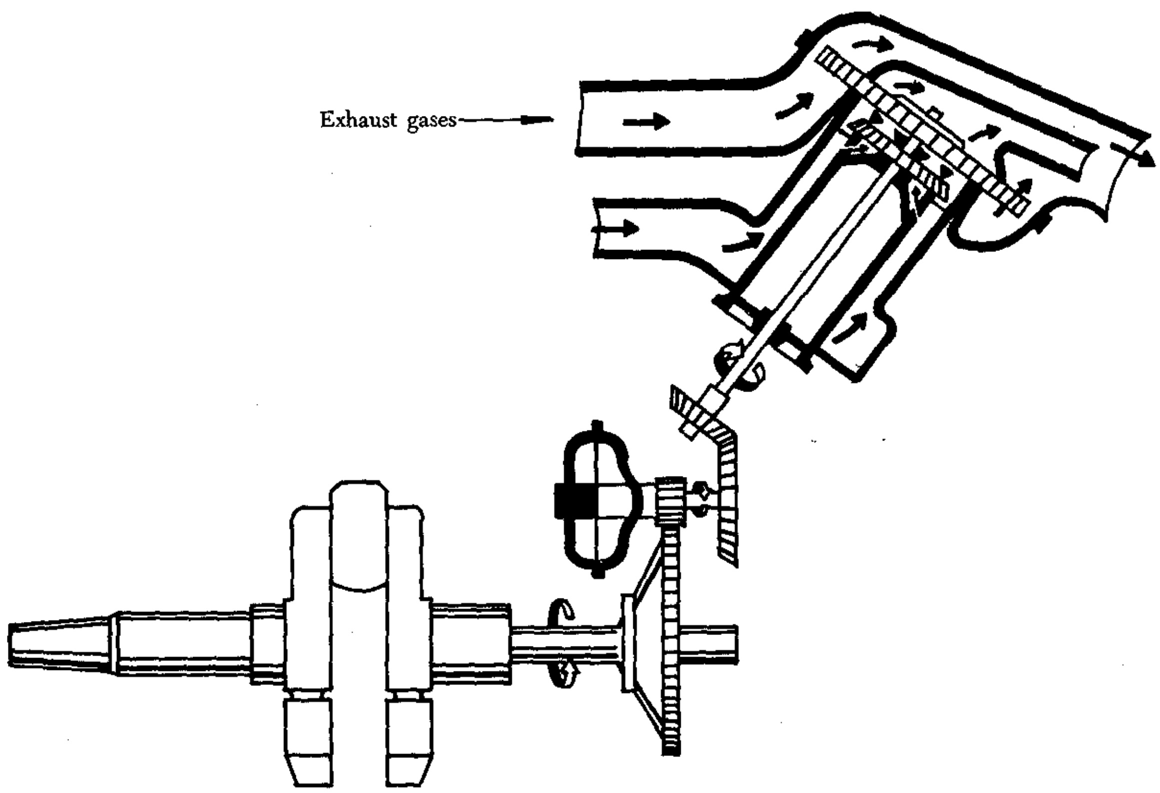



FIGURE 2–17. Transmission of turbine power to crankshaft.

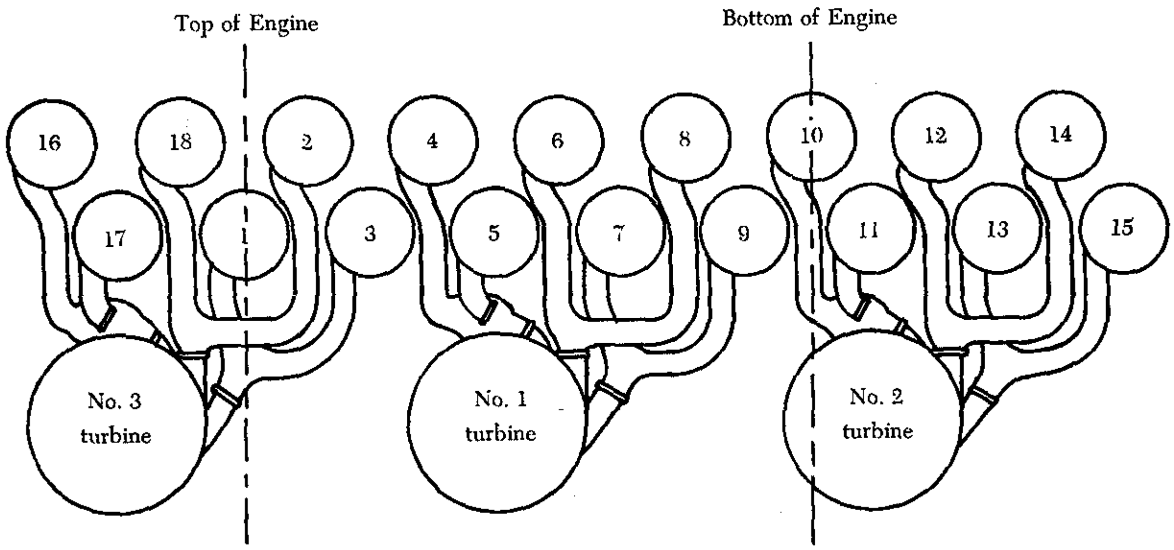



FIGURE 2–18. Schematic diagram of a PRT system.

A gas turbine engine consumes six to 10 times as much air per hour as a reciprocating engine of equivalent size. The air-entrance passage is correspondingly larger. Furthermore, it is more critical than a reciprocating engine airscoop in determining engine and aircraft performance, especially at high airspeeds. Inefficiencies of the duct result in successively magnified losses through other components of the engine.

The inlet duct has two engine functions and one aircraft function. First, it must be able to recover as much of the total pressure of the free airstream as possible and deliver this pressure to the front of the engine with a minimum loss of pressure or differential. This is known as "ram recovery" or, sometimes, as "total pressure recovery." Secondly, the duct must uniformly deliver air to the compressor inlet with as little turbulence and pressure variation as possible. As far as the aircraft is concerned, the duct must hold to a minimum the drag effect, which it creates.

Pressure drop or differential is caused by the friction of the air along both sides of the duct and by the bends in the duct system. Smooth flow depends upon keeping the amount of turbulence to a minimum as the air enters the duct. The duct must have a sufficiently straight section to ensure smooth, even airflow within. The choice of configuration of the entrance to the duct is dictated by the location of the engine within the aircraft and the airspeed, altitude, and attitude at which the aircraft is designed to operate. There are two basic types of inlet ducts, the single-entrance duct and the divided-entrance duct.

With ducts of any type, careful construction is very essential. Good workmanship is also needed when an inlet duct is repaired. Surprisingly small amounts of airflow distortion can result in appreciable loss in engine efficiency or can be responsible for otherwise unexplainable compressor stalls. Protruding rivet heads or poor sheet metal work can play havoc with an otherwise acceptable duct installation.

**Single-Entrance Duct**

The single-entrance type of duct is the simplest and most effective because the duct inlet is located directly ahead of the engine and aircraft in such a position that it scoops undisturbed air. Figure 2–19 illustrates the single-entrance duct on a single-engine, turbojet aircraft. Also, the duct can be built either in a straight configuration or with only relatively gentle curvatures. In a single-engine aircraft installation where the engine is mounted in the fuselage, the duct is necessarily long. While some pressure drop is occasioned by the long duct, the condition is offset by smooth airflow characteristics. In multi-engine installations, a short, straight duct, or one that is nearly straight, is a necessity. Although this short, straight duct results in minimum pressure drop, the engine is apt to suffer from inlet turbulence, especially at slow airspeeds or high angles of attack.

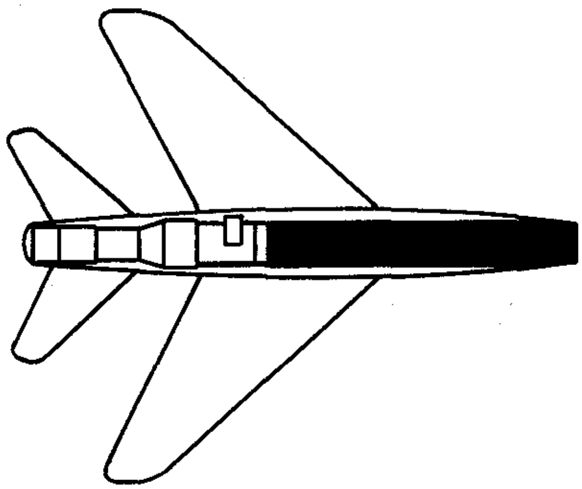


FIGURE 2–19. Aircraft with single-entrance duct.

**Divided-Entrance Duct**

The requirements of high-speed, single-engine aircraft, in which the pilot sits low in the fuselage and close to the nose, render it difficult to employ the single-entrance duct. Some form of a divided duct which takes air from either side of the fuselage may be required. This divided duct can be either a wing-root inlet or a scoop at each side of the fuselage, as shown in figure 2–20. Either type of duct presents more problems to the aircraft designer than a single-entrance duct because of the difficulty of obtaining sufficient airscoop area without imposing prohibitive amounts of drag. Internally, the problem is the same as that encountered with the single-entrance duct; that is, to construct a duct of reasonable length, yet with as few bends as possible.

The wing-root inlet on aircraft on which the wing is located fairly far aft presents a design problem because, although short, the duct must have considerable curvature to deliver air properly to the compressor inlet. Scoops at the sides of the fuselage are often used. These side scoops are placed as far forward as possible to permit a gradual bend toward the compressor inlet, making the airflow characteristics approach those of a single-entrance duct. A series of small rods is sometimes placed in the side-scoop inlet to assist in straightening the incoming airflow and to prevent turbulence.

**Variable-Geometry Duct**

The main function of an inlet duct is to furnish the proper amount of air to the engine inlet. In a typical turbojet engine, the maximum airflow requirements are such that the Mach number of the airflow directly ahead of the face of the engine is

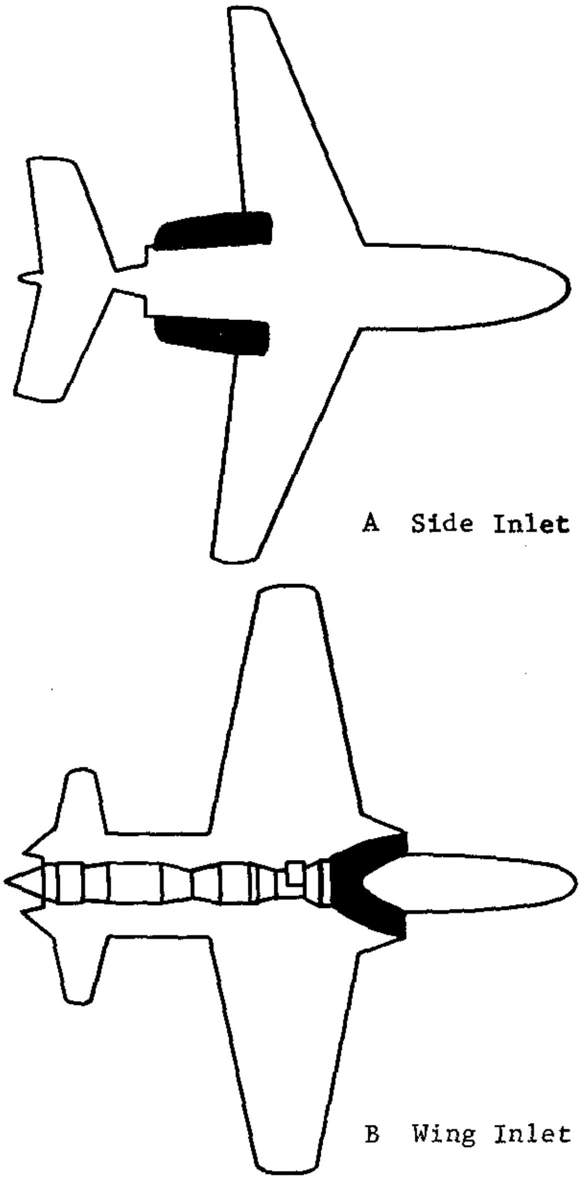



FIGURE 2–20. Two types of divided-entrance ducts.

about 0.5, or a little less. Therefore, under practically all flight conditions except takeoff or landing, the velocity of the airflow as it enters the air-inlet duct must be reduced through the duct before the same air is ready to enter the compressor. To accomplish this, inlet ducts are designed to function as diffusers, and thus decrease the velocity and increase the static pressure of the air passing through them. For subsonic multi-engine aircraft, a normal inlet duct, therefore, increases in size, front to rear, along the length of the duct, as illustrated in figure 2–21.

A supersonic diffuser progressively decreases in area in the downstream direction. Therefore, a supersonic inlet duct will follow this general config-

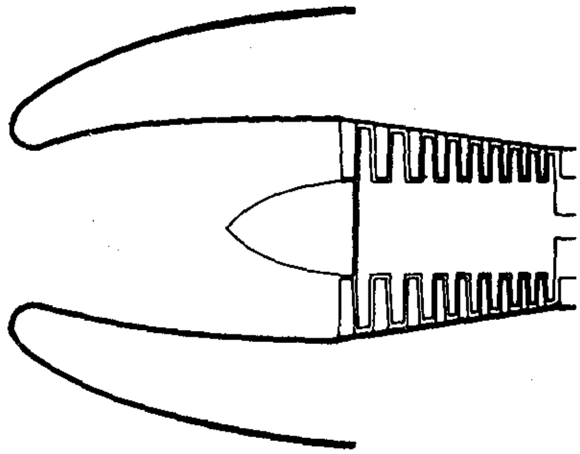


FIGURE 2–21. Divergent subsonic inlet duct.

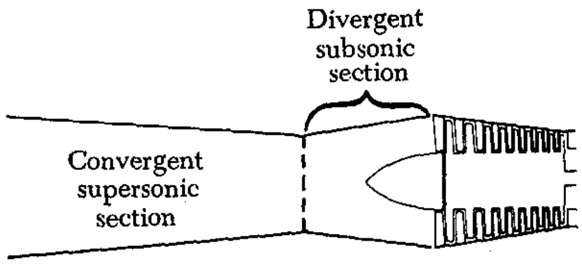



FIGURE 2–22. Supersonic inlet duct.

uration until the velocity of the incoming air is reduced to Mach 1.0. The aft section of the duct will then commence to increase in area, since this part must act as a subsonic diffuser. (See figure 2–22.) In practice, inlet ducts for supersonic aircraft will only follow this general design insofar as practical, depending upon the design features of the aircraft. For very high speed aircraft, the inside area of configuration of the duct will be changed by a mechanical device as the speed of the aircraft increases or decreases. A duct of this type is usually known as a variable-geometry inlet duct.

Two methods are used to diffuse the inlet air and slow the inlet airflow at supersonic flight speeds. One is to vary the area, or geometry, of the inlet duct either by using a movable restriction, such as a ramp or wedge, inside the duct. Still another system is some sort of a variable airflow bypass arrangement which extracts part of the inlet airflow from the duct ahead of the engine. In some cases, a combination of both systems is used.

The other method is the use of a shock wave in the airstream. A shock wave is a thin region of discontinuity in a flow of air or gas, during which the speed, pressure, density, and temperature of the air or gas undergo a sudden change. Stronger shock waves produce larger changes in the properties of the air or gas. A shock wave is willfully set up in the supersonic flow of the air entering the duct, by means of some restriction or small obstruction which automatically protrudes into the duct at high flight Mach numbers. The shock wave results in diffusion of the airflow, which, in turn, slows down the velocity of the airflow. In at least one aircraft installation, both the shock method and the variable-geometry method of causing diffusion are used in combination. The same device which changes the area of the duct also sets up a shock wave that further reduces the speed of the incoming air within the duct. The amount of change in duct area and the magnitude of the shock are varied automatically with the airspeed of the aircraft.

With a variable-geometry inlet, the so-called inlet "buzz" which sometimes occurs during flight at high Mach numbers can often be prevented by changing the amount of inlet-area variation that takes place when the variable-geometry inlet system is in operation. The "buzz" is an airflow instability which occurs when a shock wave is alternately swallowed and regurgitated by the inlet. At its worst, the condition can cause violent fluctuations in pressure through the inlet, which may result in damage to the inlet structure or, possibly, to the engine itself. A suitable variable-geometry duct will eliminate the "buzz" by increasing the stability of the airflow within the inlet duct.

### Bellmouth Compressor Inlets

Although not a duct in the true sense of the word, a bellmouth inlet is usually installed on an engine being calibrated in a ground test stand, to lead the outside static air to the inlet guide vanes of the compressor. This type of inlet is easily attached and removed. It is designed with the single objective of obtaining very high aerodynamic efficiency. Essentially, the inlet is a bell-shaped funnel having carefully rounded shoulders which offer practically no air resistance (see figure 2–23). Duct loss is so slight that it is considered zero. The engine can, therefore, be operated without the complications resulting from losses common to an installed aircraft duct. Engine performance data, such as rated thrust and thrust specific fuel consumption, are obtained while using a bellmouth compressor inlet. Usually, the inlets are fitted with protective screening. In this case, the efficiency

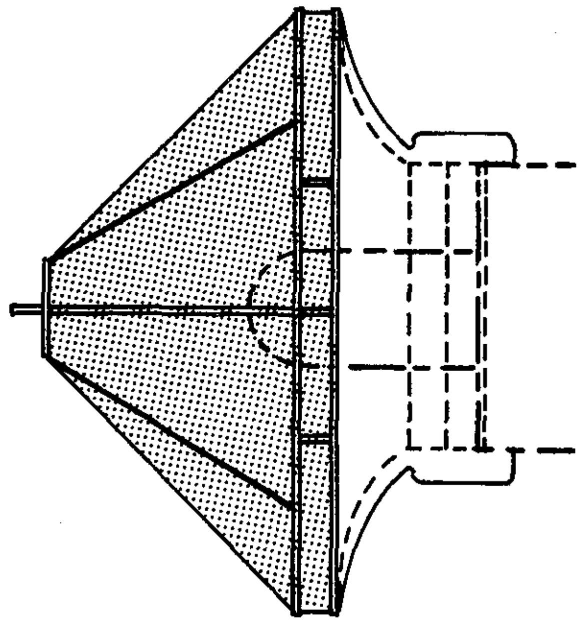


FIGURE 2–23. Bellmouth compressor inlet.

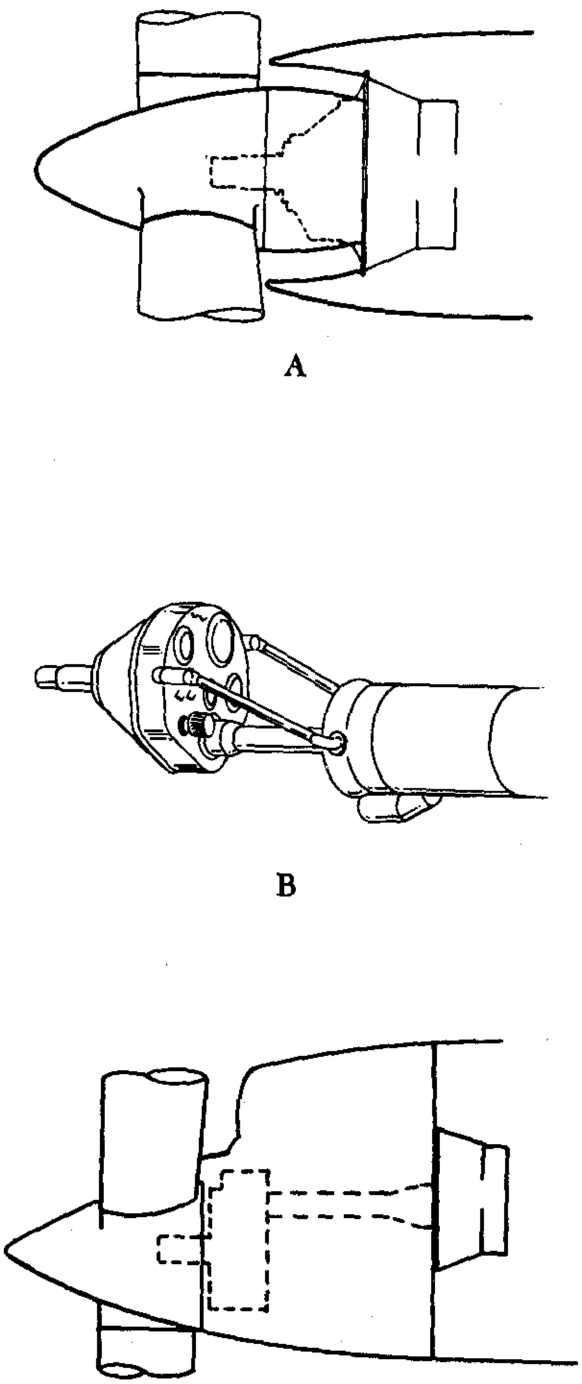
which is lost as the air passes through the screen must be taken into account when very accurate engine data are necessary.

## TURBOPROP COMPRESSOR INLETS

The air inlet on a turboprop is more of a problem than that on a turbojet because the propeller drive shaft, the hub, and the spinner must be considered in addition to the usual other inlet design factors. The ducted spinner arrangement (figure 2–24A) is generally considered the best inlet design of the turboprop engine as far as airflow and aerodynamic characteristics are concerned. However, the ducted spinner is heavier, and is more difficult to maintain and to anti-ice than the conventional streamline spinner arrangement which is frequently used. A conical spinner, which is a modified version of the streamline spinner, is sometimes employed. In either event, the arrangement of the spinner and the inlet duct is similar to that shown in figure 2–24B. When the nose section of the turboprop engine is offset from the main axis of the engine, an arrangement similar to that in figure 2–24C may be employed.

### Compressor-Inlet Screens

The appetite of a gas turbine for nuts, small bolts, rags, small hand tools, and the like, is well known. To prevent the engine from readily ingesting such items, a compressor-inlet screen is sometimes placed across the engine air inlet at some location along the inlet duct.



A

B

C

FIGURE 2–24. Turboprop compressor inlets.

The advantages and disadvantages of a screen of this type vary. If the engine is readily subject to internal damage, as would be the case for instance, of an engine having an axial compressor fitted with aluminum compressor blades, an inlet screen is almost a necessity. Screens, however, add appreciably to inlet-duct pressure loss, and are very susceptible to icing. Failures due to fatigue are also a problem. A failed screen can sometimes cause more damage than no screen at all. In some instances, inlet screens are made retractable and may be withdrawn from the airstream after takeoff or whenever icing conditions prevail. Such screens are subject to mechanical failure, and add both weight and bulk to the installation. In large engines having steel or titanium compressor blades which do not damage easily, the disadvantages of compressor screens outweigh the advantages, so they are not generally used.

### Turbofan Engine Fan Sections

Although some turbofan engines have their fan section, or blades, integral with the turbine, aft of the combustion chamber, other versions are usually constructed with the fan at the forward end of the compresser. In dual-compressor engines, the fan is integral with the relatively slow-turning, low-pressure compressor, which allows the fan blades to rotate at low tip speed for best fan efficiency. The forward fan permits the use of a conventional air-inlet duct, resulting in low inlet-duct loss. The forward fan reduces engine damage from ingested foreign material because much of any material that may be ingested will be thrown radially outward, and will pass through the fan discharge rather than through the main part of the engine.

The fan consists of one or more stages of rotating blades and stationary vanes that are somewhat larger than the forward stages of the compressor to which they are attached. The air accelerated by the fan tips forms a secondary airstream which is ducted overboard without passing through the main engine. The air which passes through the center of the fan becomes the primary airstream through the engine itself (see figure 2–25).

The air from the fan exhaust, which is ducted overboard, may be discharged in either of two ways: (1) To the outside air through short ducts, directly behind the fan, as shown in figure 2–26 and in the sketch of a bifurcated duct configuration, figure 2–27, or (2) ducted all the way to the rear of the engine, where it is exhausted to the outside air in the vicinity of the engine tailpipe.

## RECIPROCATING ENGINE EXHAUST SYSTEMS

The reciprocating engine exhaust system is fundamentally a scavenging system that collects and disposes of the high-temperature, noxious

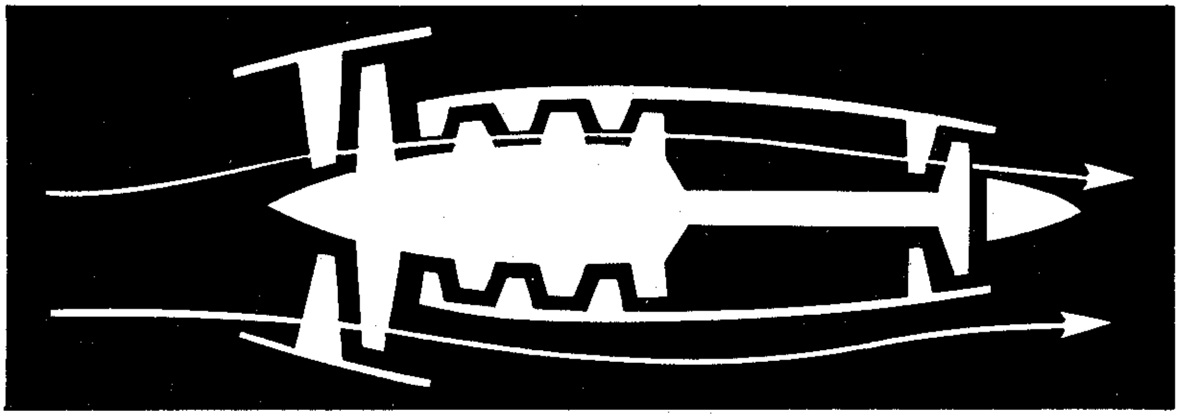


FIGURE 2–25. Airflow through a forward-fan engine.

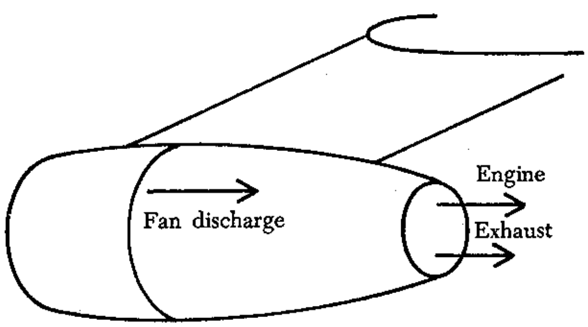



FIGURE 2–26. Typical forward-fan turbofan engine installation.

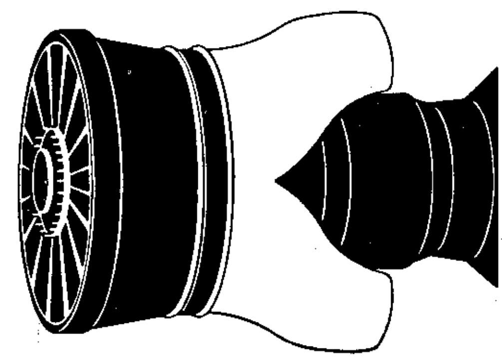


FIGURE 2–27. Bifurcated duct configuration.

gases as they are discharged by the engine. Its basic requirement is to dispose of the gases with complete safety to the airframe and the occupants of the aircraft. The exhaust system can perform many useful functions, but its first duty is to provide protection against the potentially destructive action of the exhaust gases. Modern exhaust systems, though comparatively light, adequately resist high temperatures, corrosion, and vibration to provide long, trouble-free operation with a minimum of maintenance.

There are two general types of exhaust systems in use on reciprocating aircraft engines: the short stack (open) system and the collector system. The short stack system is generally used on nonsupercharged engines and low-powered engines where noise level is not too objectionable. The collector system is used on most large nonsupercharged engines and on all turbosupercharged engines and installations where it would improve nacelle streamlining or provide easier maintenance in the nacelle area. On turbosupercharged engines the exhaust gases must be collected to drive the turbine compressor of the supercharger. Such systems have individual exhaust headers which empty into a common collector ring with only one outlet. From this outlet, the hot exhaust gas is routed via a tailpipe to the nozzle box of the turbosupercharger to drive the turbine. Although the collector system raises the back pressure of the exhaust system, the gain in horsepower from turbosupercharging more than offsets the loss in horsepower that results from increased back pressure.

The short stack system is relatively simple, and its removal and installation consists essentially of removing and installing the holddown nuts and clamps.

In figure 2–28, the location of the exhaust system components of a horizontally opposed engine is shown in a side view. The exhaust system in this installation consists of a down-stack from each cylinder, an exhaust collector tube on each side of the engine, and an exhaust ejector assembly protruding aft and down from each side of the firewall. The down-stacks are connected to the cylinders with high-temperature locknuts and

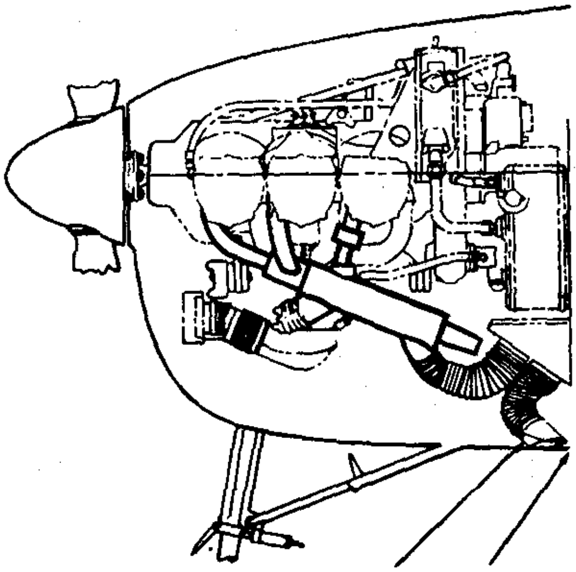
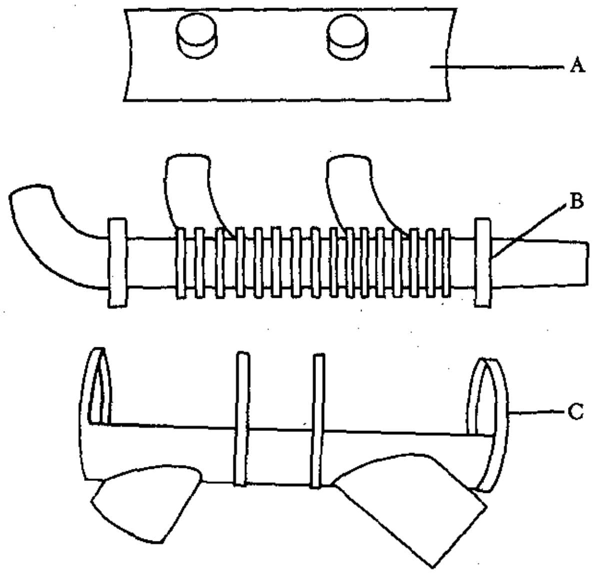


FIGURE 2–28. Exhaust system of a horizontally opposed engine.




A. Upper sheet jacket.
B. Heat exchanger collector tube.
C. Lower sheet jacket.

FIGURE 2–29. Exploded view of heater exhaust shroud assembly.

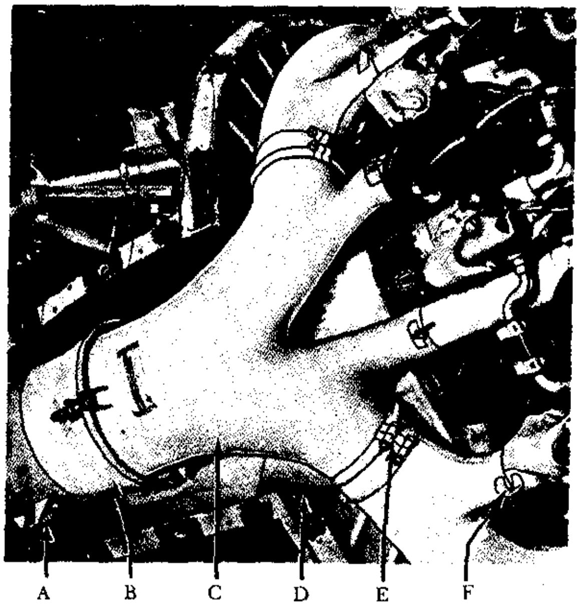
secured to the exhaust collector tube by ring clamps.

A cabin heater exhaust shroud is installed around each collector tube. (See figure 2–29.)

The collector tubes terminate at the exhaust ejector openings at the firewall and are tapered to deliver the exhaust gases at the proper velocity to induce an airflow through the exhaust ejectors. The exhaust ejectors consist of a throat and duct assembly which utilizes the pumping action of the exhaust gases to induce a flow of cooling air through all parts of the engine compartment.

### Radial Engine Exhaust Collector Ring System

Figure 2–30 shows the exhaust collector ring installed on a 14-cylinder radial engine. The collector ring is a welded corrosion-resistant steel assembly manufactured in seven sections, with each section collecting the exhaust from two cylinders. The sections are graduated in size (figure 2–31). The small sections are on the inboard side, and the largest sections are on the outboard side at the point where the tailpipe connects to the collector ring. Each section of the collector ring is bolted to a bracket on the blower section of the engine, and is partly supported by a sleeve connection between the collector ring ports and the short stack on the engine exhaust ports. The exhaust tailpipe is joined to the collector ring by a telescoping expansion joint, which allows enough slack for the removal of segments of the collector ring without removing the tailpipe.




A. Clamp assembly
B. Telescoping flange
C. Main exhaust segment
D. Engine diaphragm
E. Clamp assembly
F. Clevis pin & washer

FIGURE 2–30. Installed exhaust collector ring.

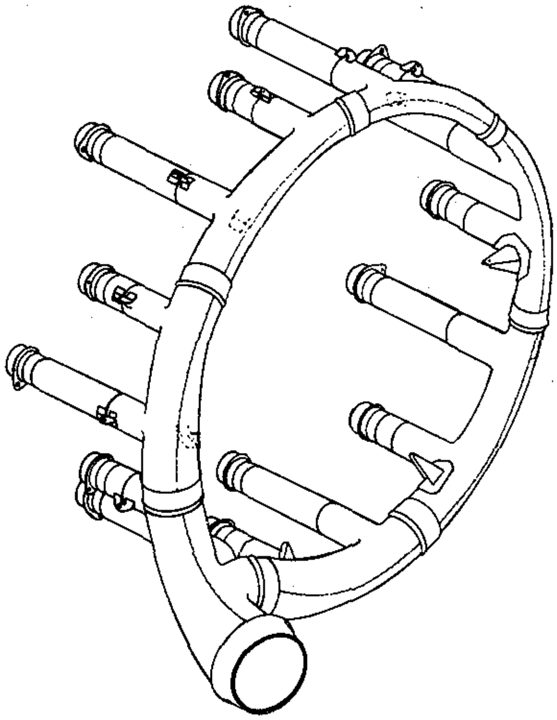


FIGURE 2–31. Exhaust collector ring.

The exhaust tailpipe is a welded, corrosion-resistant steel assembly consisting of the exhaust tailpipe and, on some aircraft, a muff-type heat exchanger.

### Manifold and Augmentor Exhaust Assembly

Some radial engines are equipped with a combination exhaust manifold and augmentor assembly. On a typical 18-cylinder engine, two exhaust assemblies and two augmentor assemblies are used. Each manifold assembly collects exhaust gases from nine cylinders and discharges the gases into the forward end of an augmentor assembly.

Four stacks of each manifold assembly are siamese exhaust stacks, each receiving the exhaust from two cylinders (see figure 2–32). The firing order of the two cylinders exhausting into each exhaust stack is as widely separated as possible. Front row cylinders are connected to stacks by port extensions.

This type of exhaust manifold is manufactured from corrosion-resistant steel, and has either a plain sandblast or a ceramic-coated finish.

The exhaust gases are directed into the augmentor bellmouths. The augmentors are designed to produce a venturi effect to draw an increased airflow over the engine to augment engine cooling.

An augmentor vane is located in each tailpipe. When the vane is fully closed, the cross-sectional area of the tailpipe is reduced by approximately 45%. The augmentor vanes are operated by an electrical actuator, and indicators adjacent to the augmentor vane switches in the cockpit show vane positions. The vanes may be moved toward the "closed" position to decrease the velocity of flow through the augmentor to raise the engine temperature.

## RECIPROCATING ENGINE EXHAUST SYSTEM MAINTENANCE PRACTICES

Any exhaust system failure should be regarded as a severe hazard. Depending on the location and type of failure, an exhaust system failure can result in carbon monoxide poisoning of crew and passengers, partial or complete loss of engine power, or an aircraft fire. Exhaust system failures generally reach a maximum rate of occurrence at 100 to 200 hours of aircraft operating time. More than 50% of all exhaust system failures occur within 400 hours.

### Exhaust System Inspection

While the type and location of exhaust system components vary somewhat with the type of aircraft, the inspection requirements for most reciprocating engine exhaust systems are very similar. The following paragraphs include a discussion of the most common exhaust system inspection items and procedures for all reciprocating engines. Figure 2–33 shows the primary inspection areas of three types of exhaust systems.

Before the removal and installation of representative exhaust systems are discussed, a precaution to be observed when performing maintenance on any exhaust system should be mentioned. Galvanized or zinc-plated tools should never be used on the exhaust system, and exhaust system parts should never be marked with a lead pencil. The lead, zinc, or galvanized mark is absorbed by the metal of the exhaust system when heated, creating a distinct change in its molecular structure. This change softens the metal in the area of the mark, causing cracks and eventual failure.

After a complete exhaust system has been installed, the air induction scoop or duct, the fuel drain lines, the cowl flaps, and all pieces of engine cowl are installed and secured. When these items have been inspected for security, the engine is operated to allow the exhaust system to heat up to

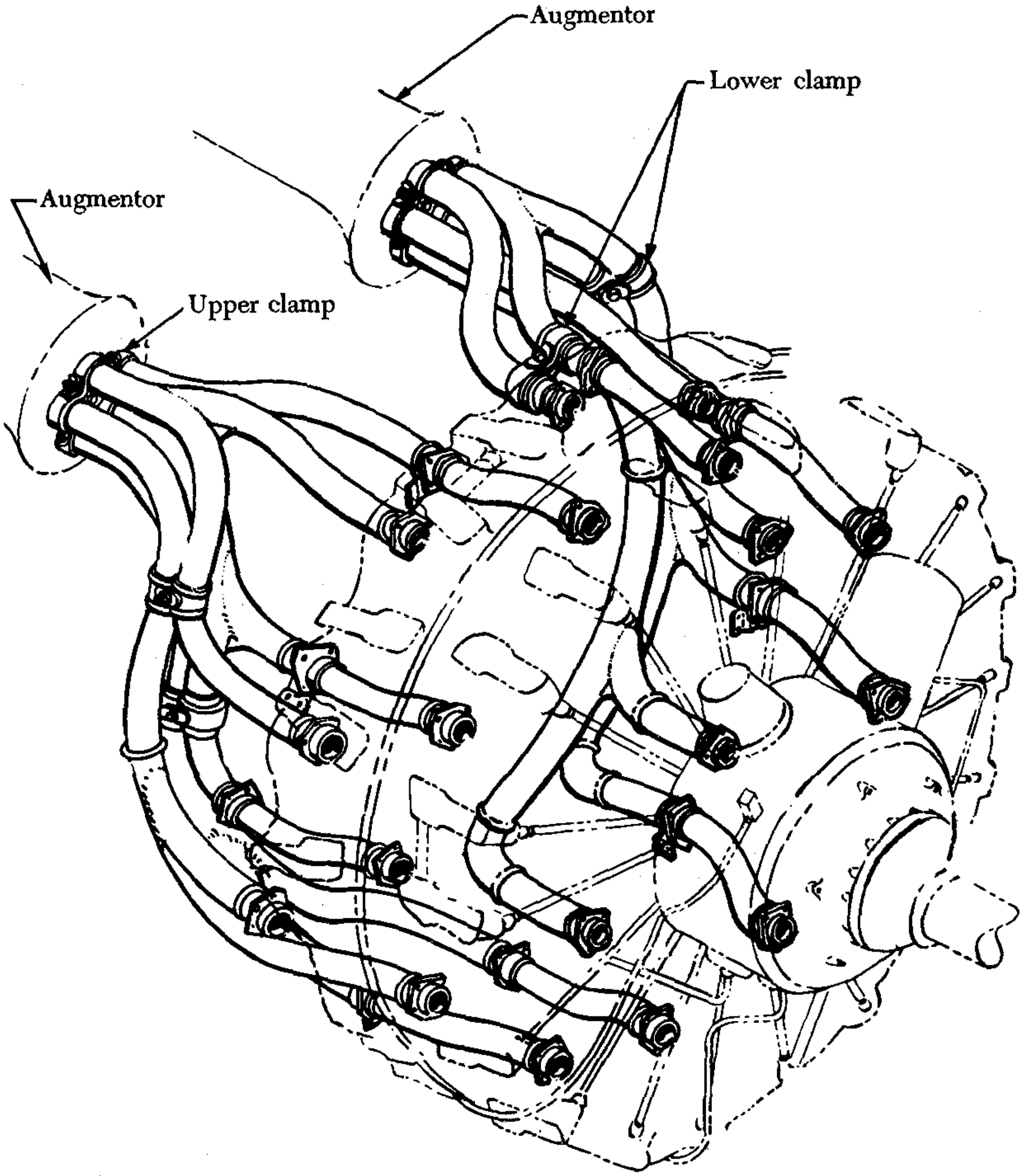



FIGURE 2–32. Exhaust manifold installation.

normal operating temperatures. The engine is then shut down and the cowling removed to expose the exhaust system.

Each clamped connection and each exhaust port connection should be inspected for evidence of exhaust gas leakage. An exhaust leak is indicated by a flat gray or a sooty black streak on the pipes in the area of the leak. An exhaust leak is usually the result of poor alignment of two mating exhaust system members. When a leaking exhaust connection is discovered, the clamps should be loosened and the leaking units repositioned to ensure a gas-

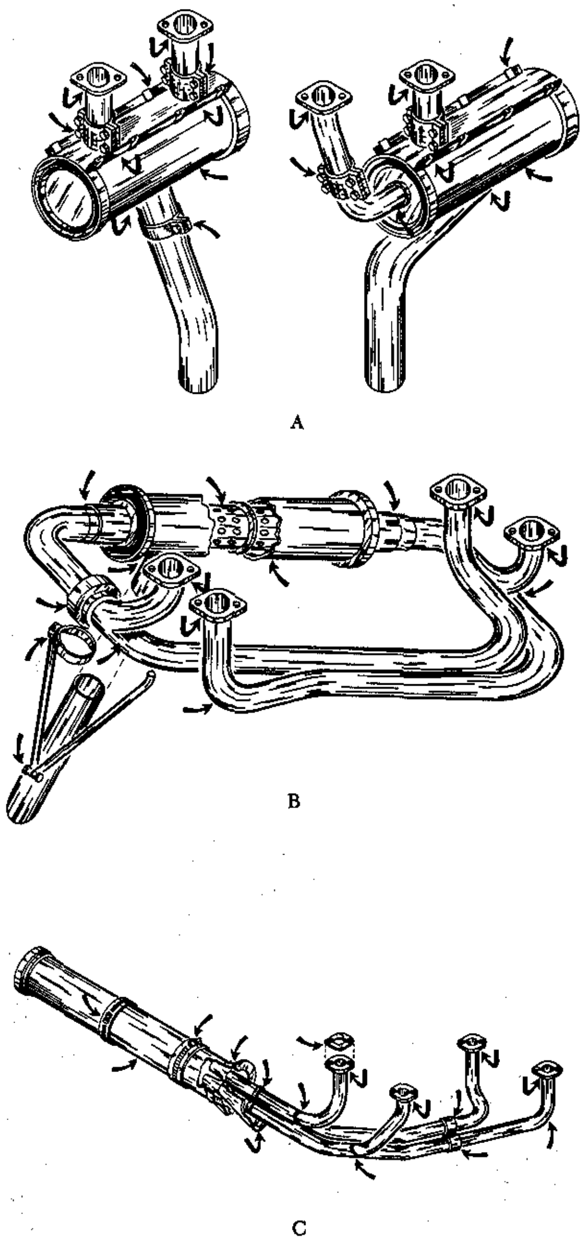



FIGURE 2–33. Primary inspection areas (A. Separate system; B. Crossover-type system; C. Exhaust/augmentor system.)

tight fit. After repositioning, the system nuts should be re-tightened enough to eliminate any looseness without exceeding the specified torque. If tightening to the specified torque does not eliminate looseness, the bolts and nuts should be replaced, since they have probably stretched. After tightening to the specified torque, all nuts should be safetied.

With the cowling removed, all necessary cleaning operations can be performed. Some exhaust units are manufactured with a plain sandblast finish. Others may have a ceramic-coated finish. Ceramic-coated stacks should be cleaned by degreasing only. They should never be cleaned with sandblast or alkali cleaners.

During the inspection of an exhaust system, close attention should be given to all external surfaces of the exhaust system for cracks, dents, or missing parts. This also applies to welds, clamps, supports, and support attachment lugs, bracing, slip joints, stack flanges, gaskets, and flexible couplings. Each bend should be examined, as well as areas adjacent to welds; and any dented areas or low spots in the system should be inspected for thinning and pitting due to internal erosion by combustion products or accumulated moisture. An ice pick or similar pointed instrument is useful in probing suspected areas. The system should be disassembled as necessary to inspect internal baffles or diffusers.

If a component of the exhaust system is inaccessible for a thorough visual inspection or is hidden by nonremovable parts, it should be removed and checked for possible leaks. This can often best be accomplished by plugging the openings of the component, applying a suitable internal pressure (approximately 2 p.s.i.), and submerging it in water. Any leaks will cause bubbles that can be readily detected.

The procedures required for an installation inspection are also performed during most regular inspections. Daily inspection of the exhaust system usually consists of checking the exposed exhaust system for cracks, scaling, excessive leakage, and loose clamps.

#### Muffler and Heat Exchanger Failures

Approximately half of all muffler and heat exchanger failures can be traced to cracks or ruptures in the heat exchanger surfaces used for cabin and carburetor heat sources. Failures in the heat exchanger surface (usually in the outer wall) allow exhaust gases to escape directly into the cabin heat system. These failures, in most cases, are caused by thermal and vibration fatigue cracking in areas of stress concentration.

Failure of the spot-welds which attach the heat transfer pins can result in exhaust gas leakage. In addition to a carbon monoxide hazard, failure of heat exchanger surfaces can permit exhaust gases to be drawn into the engine induction system, causing engine overheating and power loss.

### Exhaust Manifold and Stack Failures

Exhaust manifold and stack failures are usually fatigue failures at welded or clamped points; for example, stack-to-flange, stack-to-manifold, and crossover pipe or muffler connections. Although these failures are primarily fire hazards, they also present carbon monoxide problems. Exhaust gases can enter the cabin via defective or inadequate seals at firewall openings, wing strut fittings, doors, and wing root openings.

### Internal Muffler Failures

Internal failures (baffles, diffusers, etc.) can cause partial or complete engine power loss by restricting the flow of the exhaust gases. As opposed to other failures, erosion and carburization caused by the extreme thermal conditions are the primary causes of internal failures. Engine backfiring and combustion of unburned fuel within the exhaust system are probable contributing factors. In addition, local hot-spot areas caused by uneven exhaust gas flow can result in burning, bulging, or rupture of the outer muffler wall.

### Exhaust Systems with Turbocharger

When a turbocharger or a turbosupercharger system is included, the engine exhaust system operates under greatly increased pressure and temperature conditions. Extra precautions should be taken in exhaust system care and maintenance. During high-pressure altitude operation, the exhaust system pressure is maintained at or near sea level values. Due to the pressure differential, any leaks in the system will allow the exhaust gases to escape with torch-like intensity that can severely damage adjacent structures.

A common cause of malfunction is coke deposits (carbon buildup) in the waste gate unit causing erratic system operation. Excessive deposit buildups may cause the waste gate valve to stick in the "closed" position, causing an overboost condition. Coke deposit buildup in the turbo itself will cause a gradual loss of power in flight and low manifold pressure reading prior to takeoff. Experience has shown that periodic de-coking, or removal of carbon deposits, is necessary to maintain peak efficiency. Clean, repair, overhaul, and adjust the system components and controls in accordance with the applicable manufacturer's instructions.

### Augmentor Exhaust System

On exhaust systems equipped with augmentor tubes, the augmentor tubes should be inspected at regular intervals for proper alignment, security of attachment, and general overall condition. Even where augmentor tubes do not contain heat exchanger surfaces, they should be inspected for cracks along with the remainder of the exhaust system. Cracks in augmentor tubes can present a fire or carbon monoxide hazard by allowing exhaust gases to enter the nacelle, wing, or cabin areas.

### Exhaust System Repairs

It is generally recommended that exhaust stacks, mufflers, tailpipes, etc., be replaced with new or reconditioned components rather than repaired. Welded repairs to exhaust systems are complicated by the difficulty of accurately identifying the base metal so thet the proper repair materials can be selected. Changes in composition and grain structure of the original base metal further complicate the repair.

However, when welded repairs are necessary, the original contours should be retained; the exhaust system alignment must not be warped or otherwise affected. Repairs or sloppy weld beads which protrude internally are not acceptable as they cause local hot-spots and may restrict exhaust gas flow. When repairing or replacing exhaust system components, the proper hardware and clamps should always be used. Steel or low-temperature, self-locking nuts should not be substituted for brass or special high-temperature locknuts used by the manufacturer. Old gaskets should never be re-used. When disassembly is necessary, gaskets should be replaced with new ones of the same type provided by the manufacturer.

## TURBINE ENGINE EXHAUST DUCTS

The term "exhaust duct" is applied to the engine exhaust pipe, or tailpipe, which connects the turbine outlet to the jet nozzle of a non-afterburning engine. Although an afterburner might also be considered a type of exhaust duct, afterburning is a subject in itself which is discussed later in this chapter.

If the engine exhaust gases could be discharged directly to the outside air in an exact axial direction at the turbine exit, an exhaust duct might not be necessary. This, however, is not practical. A larger total thrust can be obtained from the engine if the gases are discharged from the aircraft at a higher velocity than is permissible at the turbine outlet. An exhaust duct is therefore added, both to collect and straighten the gas flow as it comes from the turbine and to increase the velocity of the gases before they are discharged from the exhaust nozzle at the rear of the duct. Increasing the velocity of the gases increases their momentum and increases the thrust produced.

An engine exhaust duct is often referred to as the engine tailpipe; although the duct, itself, is essentially a simple, stainless steel, conical or cylindrical pipe. The assembly also includes an engine tailcone and the struts inside the duct. The tailcone and the struts add strength to the duct, impart an axial direction to the gas flow, and smooth the gas flow.

Immediately aft of the turbine outlet, and usually just forward of the flange to which the exhaust duct is attached, the engine is instrumented for turbine discharge pressure. One or more pressure probes are inserted into the exhaust duct to provide adequate sampling of the exhaust gases. In large engines, it is not practical to measure the internal temperature at the turbine inlet, so the engine is often also instrumented for exhaust gas temperature at the turbine outlet.

### Conventional Convergent Exhaust Nozzle

The rear opening of a turbine engine exhaust duct is called the exhaust nozzle (figure 2–34). The nozzle acts as an orifice, the size of which determines the density and velocity of the gases as they emerge from the engine.

In most non-afterburning engines the exhaust nozzle area is quite critical. Adjusting the area of the exhaust nozzle will change both the engine performance and the exhaust gas temperature. Some engines are trimmed to their correct exhaust gas temperature by altering the exhaust nozzle area. When this is the case, small tabs, which may be bent as required, are provided on the exhaust duct at the nozzle opening; or small, adjustable pieces called "mice" are fastened, as needed, around the perimeter of the nozzle to change the area.

### Convergent-Divergent Exhaust Nozzle

Whenever the engine pressure ratio is high enough to produce exhaust gas velocities which might exceed Mach 1 at the engine exhaust nozzle, more thrust can be gained by using a convergent-divergent type of nozzle (figure 2–5). The advantage of a convergent-divergent nozzle is greatest at high Mach numbers because of the resulting higher pressure ratio across the engine exhaust nozzle.

To ensure that a constant weight or volume of a gas will flow past any given point after sonic velocity is reached, the rear part of a supersonic exhaust duct is enlarged to accommodate the additional weight or volume of a gas that will flow at supersonic rates. If this is not done, the nozzle will not operate efficiently. This section of the exhaust duct is known as divergent.

When a divergent duct is used in combination with a conventional exhaust duct, it is called a convergent-divergent exhaust duct. In the convergent-divergent, or C-D nozzle, the convergent section is designed to handle the gases while they remain subsonic, and to deliver the gases to the throat of the nozzle just as they attain sonic velocity. The divergent section handles the gases, further increasing their velocity, after they emerge from the throat and become supersonic.

## TURBOPROP EXHAUST SYSTEM

In a typical turboprop exhaust system, the exhaust gases are directed from the turbine section

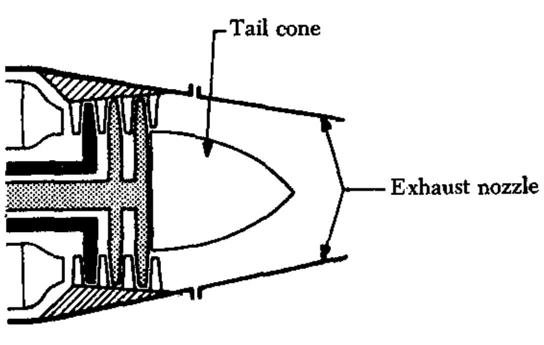



FIGURE 2–34. Conventional convergent exhaust duct.

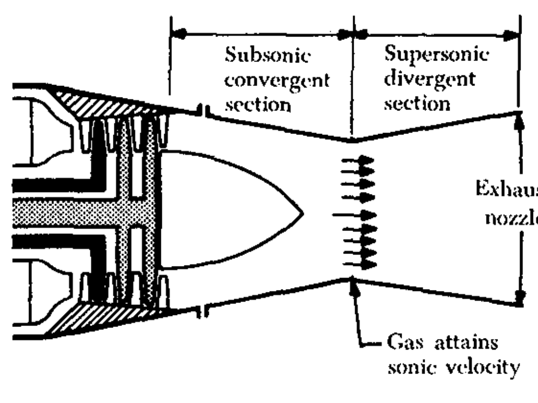



FIGURE 2–35. Convergent-divergent exhaust duct (nozzle).

of the engine to the atmosphere through a tailpipe assembly.

In a typical installation the tailpipe assembly is mounted in the nacelle and is attached at its forward end to the firewall. The forward section of the tailpipe is funnel shaped and surrounds but does not contact the turbine exhaust section. This arrangement forms an annular gap which serves as an air ejector for the air surrounding the engine hot section. As the high-velocity exhaust gases enter the tailpipe, a low pressure effect is produced which causes the air around the engine hot section to flow through the annular gap into the tailpipe.

An exhaust tailpipe of this type is usually manufactured in two sections (see figure 2–36). Both the forward funnel-shaped section and the rear section are made of corrosion-resistant steel, and a corrosion-resistant, high-temperature clamp secures the two sections together in a gastight joint.

The mounting flange welded to the forward edge of the forward tailpipe section mates to the engine side of the firewall and is secured to it with screws. An integral bellows section permits expansion between the firewall and two fixed bearing fittings, which can be adjusted to move the tailpipe in a vertical plane.

The rear section of the tailpipe is secured to the airframe by two support arms, one on each side of the tailpipe. The support arms are attached to the upper surface of the wing in such a way that free movement fore and aft is permitted to compensate for expansion.

The tailpipe assembly is wrapped in an insulating blanket to shield the surrounding area from the high heat produced by the exhaust gases. Such blankets may be made of stainless steel laminated sheet on the outside and fiber glass on the inside.

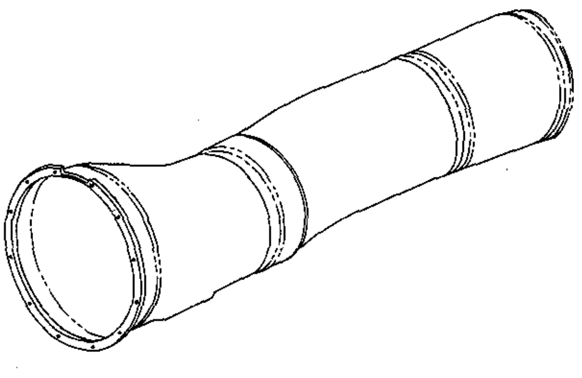


FIGURE 2–36. Two-section turboprop exhaust tailpipe.

## THRUST REVERSERS

The difficult problem of stopping an aircraft after landing greatly increases with the higher airspeeds and greater gross weights, common to most of the larger, modern aircraft, which result in higher wing loadings and increased landing speeds. In many instances, wheel brakes can no longer be entirely relied upon to slow the aircraft within a reasonable distance, immediately after touchdown. The reversible pitch propeller has solved the problem for reciprocating-engine and turboprop-powered airplanes. Commercial turbojet aircraft, however, must rely upon reversing the thrust produced by their engines.

An engine thrust reverser (see figure 2–37) not only provides a ground-speed braking force, but, if suitable, is desirable for in-flight use prior to landing. Some means of slowing the airspeed and increasing the rate of sink during descent, such as a dive brake, some form of wing spoiler, or a thrust reverser that can be used while airborne, is almost a necessity for turbojet aircraft.

Many forms of thrust reversers have been proposed, and quite a number have been tested with a considerable degree of success. The most successful thrust reversers can be divided into two categories, the mechanical-blockage type and the aerodynamic-blockage type. Mechanical blockage is accomplished by placing a removable obstruction in the exhaust gas stream, usually somewhat to the rear of the nozzle. The engine exhaust gases are mechanically blocked and diverted at a suitable angle in the reverse direction by an inverted cone, half-sphere, or other means of obstruction, which is placed in position to reverse the flow of exhaust gases. In the aerodynamic-blockage type of thrust reverser, thin airfoils or obstructions are placed in the gas stream, either along the length of the exhaust duct or immediately aft of the exhaust nozzle. In one adaptation of the aerodynamic reverser, vanes inside the duct create swirling of the gases in a manner which centrifuges them into a cascade of turning vanes. At least one current-model, commercial turbojet aircraft uses a combination of the mechanical-blockage and

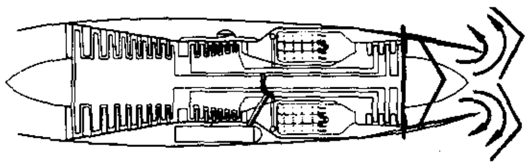


FIGURE 2–37. Operation of the thrust reverser.

aerodynamic-blockage type reversers.

A thrust reverser must not affect engine operation either when the reverser is operating or when it is not. It must be able to withstand high temperatures, and must be mechanically strong, relatively light in weight, reliable, and "fail-safe." When not in use, it should not add appreciably to the engine frontal area, and must be streamlined into the configuration of the engine nacelle. To satisfy the minimum braking requirements after landing, a thrust reverser should be able to produce in reverse at least 50% of the full forward thrust of which the engine is capable.

The clamshell-type of mechanical-blockage reverser (figure 2–38) adequately satisfies most of these requirements and, in one form or another, has been adopted for use on non-afterburning engines. At throttle positions below idle, the reverser operates to form a turning barrier in the path of escaping exhaust gases, which, in turn, nullifies and reverses the forward thrust of the engine. Throttle positions below idle cause the engine to accelerate in controllable amounts up to full r.p.m. so that either partial or full reverse thrust may be used at will. When the reverser is not in use, the clamshell doors retract and nest neatly around the engine exhaust duct, usually forming the rear section of the engine nacelle. Most thrust reversers in use at this time are combined with an engine exhaust silencer.

## Engine Noise Suppressors

Aircraft powered by large turbojet engines require some sort of silencing device or noise suppressor for the engine exhaust gases when operating from airports located in or near thickly populated areas. Two types of noise suppressors are used, one being a portable device, separate from the aircraft, for use on the ground by maintenance activities; it is positioned at the rear of an engine

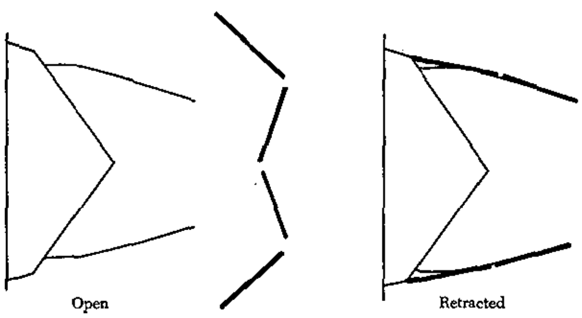



FIGURE 2–38. Mechanical blockage thrust reverser.

whenever prolonged engine operation is anticipated. The other type of noise suppressor is an integral, airborne part of the aircraft engine installation or engine tailpipe. Only this latter form of suppressor, which primarily suppresses engine noise during takeoff, climb, approach, and landing, will be discussed here.

It is generally accepted that the amount of sound attenuation required for turbojet aircraft will be the amount necessary to moderate the engine noise to a level which will be no more objectionable than the noise produced by a reciprocating engine and propeller combination, operating under similar conditions. Although the amount of attenuation necessary is usually about 12 decibels, the manner in which the noise of a turbojet aircraft can be reduced to a level that is as acceptable as that of a reciprocating-engine aircraft is not simple to determine. The propeller, which is a major source of noise in reciprocating-engine aircraft, has a noise pattern which rises sharply to a maximum level as the plane of the propeller passes an individual on the ground, and then drops off almost as sharply after the propeller has gone by. The turbojet aircraft produces a sharp rise in noise, which reaches a peak after the aircraft has passed an individual on the ground, and is at an angle of approximately 45° to him. The noise then persists at a high level for a considerable period of time as compared with that of a reciprocating engine with a propeller (see figure 2–39).

There are three sources of noise involved in the operation of a gas turbine engine. The engine air intake and vibration from engine housing are sources of some noise, but the noise thus generated does not compare in magnitude with that produced by the engine exhaust as illustrated in figure 2–40. The noise produced by the engine exhaust is caused by the high degree of turbulence of a high-velocity jet stream moving through a relatively quiet atmosphere.

For a distance of a few nozzle diameters downstream behind the engine, the velocity of the jet stream is high, and there is little mixing of the atmosphere with the jet stream. In this region, the turbulence within the high-speed jet stream is a very fine grain turbulence, and produces relatively high-frequency noise.

Farther downstream, as the velocity of the jet stream slows down, the jet stream mixes with the atmosphere, and turbulence of a coarser type begins. Compared with noise from other portions of

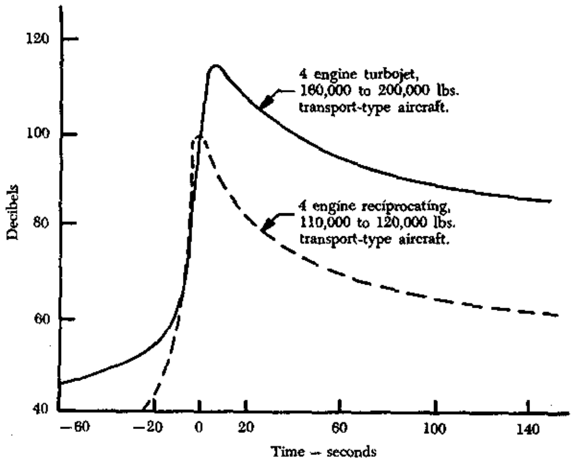



FIGURE 2–39. Noise levels.

the jet stream, noise from this portion has a much lower frequency. As the energy of the jet stream finally is dissipated in large turbulent swirls, a greater portion of the energy is converted into noise. The noise generated as the exhaust gases dissipate is at a frequency near the low end of the audible range. The lower the frequency of the noise, the greater the distance that it will travel. This means that the low-frequency noises will reach an individual on the ground in greater volume than the high-frequency noises, and hence will be more objectionable. High-frequency noise is weakened more rapidly than low-frequency noise, both by distance and the interference of buildings, terrain, and atmospheric disturbances. A deep-voiced, low-frequency foghorn, for example, may be heard much farther than a shrill, high-frequency whistle, even though both may have the same over-all volume (decibels) at their source.

Noise levels vary with engine thrust and are proportional to the amount of work done by the engine on the air which passes through it. An engine having relatively low airflow but high thrust due to high turbine discharge (exhaust gas) temperature, pressure, and/or afterburning will produce a gas stream of high velocity and therefore high noise levels. A larger engine, handling more air, will be quieter at the same thrust. Thus, the noise level can be considerably reduced by operating the engine at lower power settings, and large engines operating at partial thrust will be less noisy than smaller engines operating at full thrust.

Compared with a turbojet, a turbofan version of the same engine will be quieter during takeoff. The noise level produced by a fan-type engine is less, principally because the exhaust gas velocities ejected at the engine tailpipe are slower than those for a turbojet of comparative size.

Fan engines require a larger turbine to provide additional power to drive the fan. The large turbine, which usually has an additional turbine stage, reduces the velocity of the gas and therefore reduces the noise produced, because exhaust gas noise is proportional to exhaust gas velocity. The exhaust from the fan, itself, is at a relatively low velocity, and therefore does not create a noise problem.

Because of the characteristic of low-frequency noise to linger at a relatively high volume, effective noise reduction for a turbojet aircraft must be

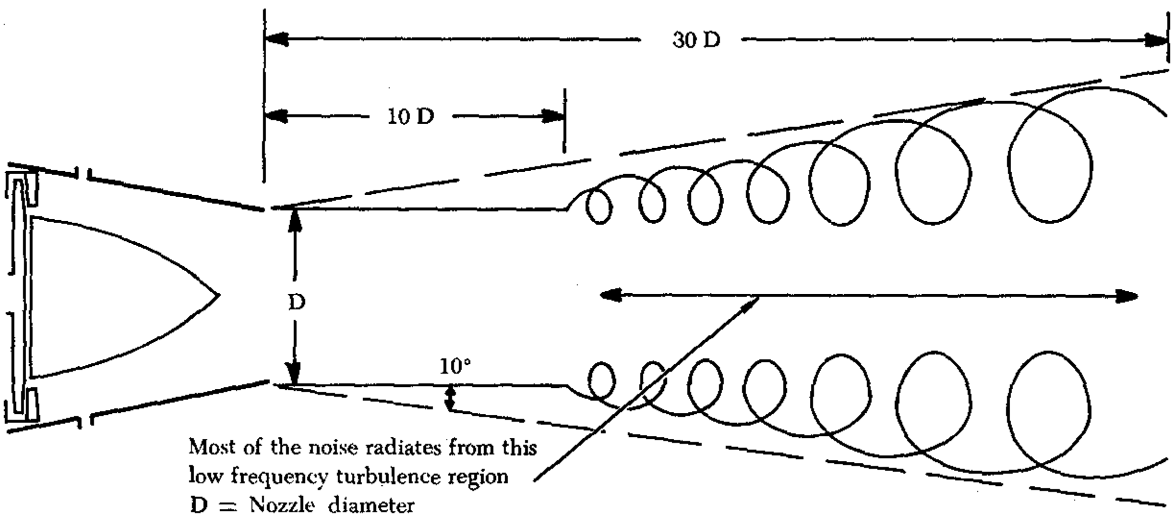



FIGURE 2–40. Turbojet exhaust noise pattern.

achieved by revising the noise pattern or by changing the frequency of the noise emitted by the jet nozzle.

The noise suppressors in current use are either of the corrugated-perimeter type, shown in figure 2–41, or the multi-tube type, shown in figure 2–42. Both types of suppressors break up the single, main jet exhaust stream into a number of smaller jet streams. This increases the total perimeter of the nozzle area and reduces the size of the eddies created as the gases are discharged into the open air. Although the total noise-energy remains unchanged, the frequency is raised considerably. The size of the eddies scales down, at a linear rate, with the size of the exhaust stream. This has two effects. First, the change in frequency may put some of the noise above the audibility range of the human ear, and, secondly, high frequencies within the audible range, while perhaps more annoying, are more highly attenuated by atmospheric absorption than are low frequencies. Thus, the falloff in intensity is greater and the noise level is less at any given distance from the aircraft.

## ENGINE AIR-INLET VORTEX DESTROYER

When turbojet engines are operating on the ground, an engine air-inlet vortex can sometimes

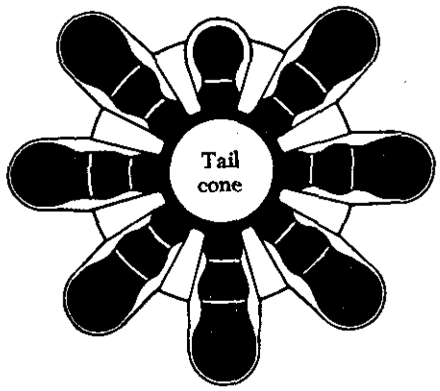



FIGURE 2–41. Rear view of corrugated-perimeter noise suppressor.

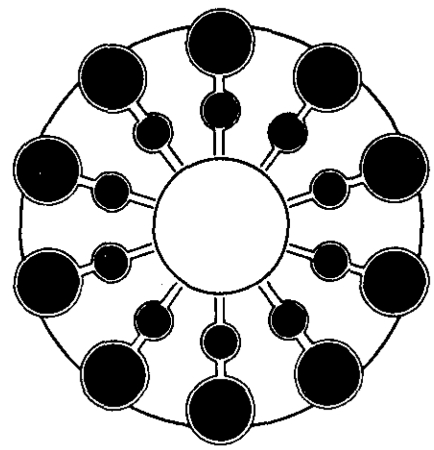


FIGURE 2–42. Rear view of multi-tube noise suppressor.

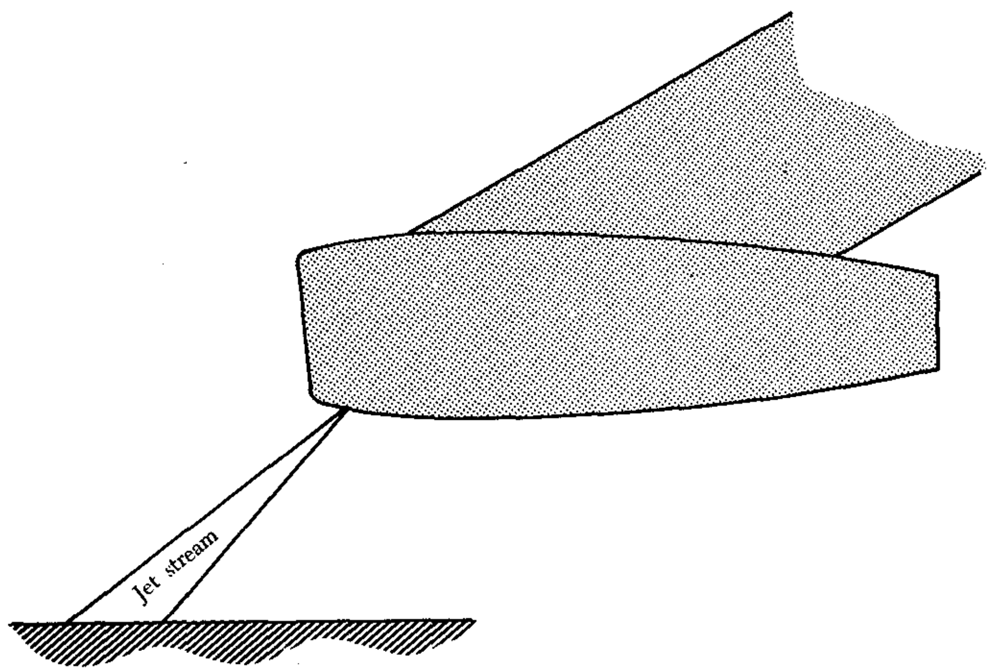



FIGURE 2–43. Inlet vortex destroyer jet stream.

form between the engine air inlet and the ground. This vortex can cause a strong suction force capable of lifting small foreign objects from the ground into the engine inlet. The ingestion of such debris can cause engine damage or even failure.

To minimize the ingestion of runway debris, some turbojet engines are equipped with an engine air-inlet vortex destroyer. This destroyer is a small jet stream directed downward from the lower leading edge of the noise cowl to the ground to destroy the swirling vortex base. Figure 2–43 illustrates the general direction and size of the vortex-destroying jet blast.

Figure 2–44 is a diagram showing the location of the jet stream nozzle and the control valve. Bleed air from the engine is used as the vortex-destroying air stream. It is controlled by a valve located in the nose cowl. The control valve is usually a two-position valve that is opened by a landing gear safety switch. The valve closes when the aircraft leaves the runway and the weight of the aircraft is removed from the landing gear.

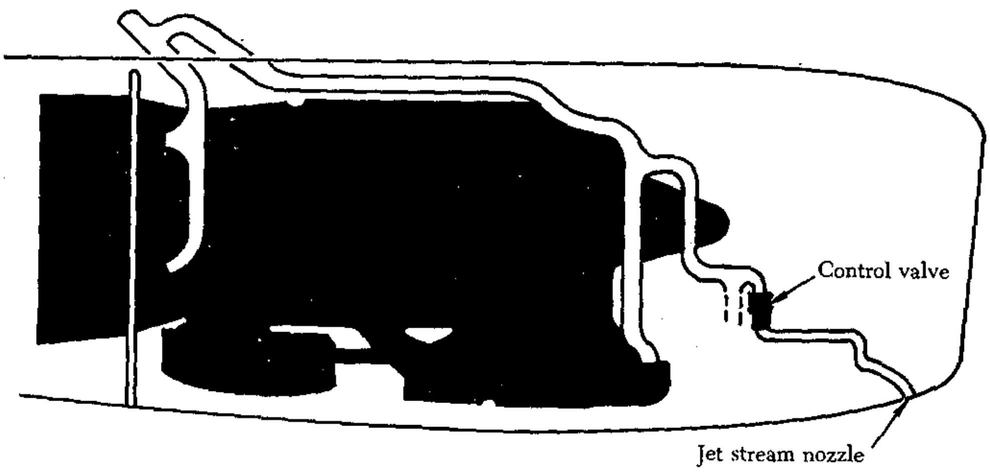



FIGURE 2–44. Location of vortex destroyer components.